EXHIBITS TO BOBWHITE'S RESPONSES TO SITING BOARD STAFF REQUESTS

Exhibit A	Health and Safety Impacts of Solar Photovoltaics PV
Exhibit B	Balancing Agricultural Productivity with Ground Based Solar Photovoltaic PV Development
Exhibit C	A Brief History of Solar Panels
Exhibit D	Study of Acoustic and EMF Levels from Solar Photovoltaic Projects
Exhibit E	A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems
Exhibit F	General Design Procedures for Airport-Based Solar Photovoltaic Systems
Exhibit G	Clean Energy Results: Questions & Answers Ground-Mounted Solar Photovoltaic Systems
Exhibit H	Technical Guidance for Evaluating Selected Solar Technologies on Airports
Exhibit I	Implementing Solar Technologies at Airports
Exhibit J	Federal Aviation Administration; Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports
Exhibit K	Lease Agreements (Confidential)

EXHIBITS TO BOBWHITE'S RESPONSES TO HARVEY ECONOMICS' REQUESTS

II. Site Development Plan

Exhibit L Updated Land Control Map

IV. Property Value and Land Use

Exhibit M Updated Kirkland Letter

V. Traffic

Exhibit N Map of Primary Roads

VII. Noise

Exhibit O	Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety
Exhibit P	NBW Sound Study

VIII. Topography/Scenery

Exhibit Q	Master Plant List
Exhibit R	Landscaping Maps
Exhibit S	Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach
Exhibit T	Solar and Glare Fact Sheet

IX. Public Meeting Materials

Exhibit U	Information Sheet
Exhibit V	Full Transcript of Public Information Meeting

XI. Economic Analysis

Exhibit W	Annual Salary Level (Confidential)
Exhibit X	Annual Expenditures (Confidential)
Exhibit Y	Form of PILOT Agreement

Exhibit A

Health and Safety Impacts of Solar Photovoltaics PV

WHITE PAPER

Health and Safety Impacts of Solar Photovoltaics

By Tommy Cleveland

May 2017

NC CLEAN ENERGY TECHNOLOGY CENTER

NC STATE UNIVERSITY

Contents

Health and Safety Impacts of Solar Photovoltaics

The increasing presence of utility-scale solar photovoltaic (PV) systems (sometimes referred to as solar farms) is a rather new development in North Carolina's landscape. Due to the new and unknown nature of this technology, it is natural for communities near such developments to be concerned about health and safety impacts. Unfortunately, the quick emergence of utility-scale solar has cultivated fertile grounds for myths and half-truths about the health impacts of this technology, which can lead to unnecessary fear and conflict.

Photovoltaic (PV) technologies and solar inverters are not known to pose any significant health dangers to their neighbors. The most important dangers posed are increased highway traffic during the relative short construction period and dangers posed to trespassers of contact with high voltage equipment. This latter risk is mitigated by signage and the security measures that industry uses to deter trespassing. As will be discussed in more detail below, risks of site contamination are much less than for most other industrial uses because PV technologies employ few toxic chemicals and those used are used in very small quantities. Due to the reduction in the pollution from fossil-fuel-fired electric generators, the overall impact of solar development on human health is overwhelmingly positive. This pollution reduction results from a partial replacement of fossil-fuel fired generation by emission-free PV-generated electricity, which reduces harmful sulfur dioxide (SO2), nitrogen oxides (NOx), and fine particulate matter (PM2.5). Analysis from the National Renewable Energy Laboratory and the Lawrence Berkeley National Laboratory, both affiliates of the U.S. Department of Energy, estimates the health-related air quality benefits to the southeast region from solar PV generators to be worth 8.0 ¢ per kilowatt-hour of solar generation.[1] This is in addition to the value of the electricity and suggests that the air quality benefits of solar are worth more than the electricity itself.

Even though we have only recently seen large-scale installation of PV technologies, the technology and its potential impacts have been studied since the 1950s. A combination of this solar-specific research and general scientific research has led to the scientific community having a good understanding of the science behind potential health and safety impacts of solar energy. This paper utilizes the latest scientific literature and knowledge of solar practices in N.C. to address the health and safety risks associated with solar PV technology. These risks are extremely small, far less than those associated with common activities such as driving a car, and vastly outweighed by health benefits of the generation of clean electricity.

This paper addresses the potential health and safety impacts of solar PV development in North Carolina, organized into the following four categories:
(1) Hazardous Materials
(2) Electromagnetic Fields (EMF)
(3) Electric Shock and Arc Flash
(4) Fire Safety

1 • Hazardous Materials

One of the more common concerns towards solar is that the panels (referred to as "modules" in the solar industry) consist of toxic materials that endanger public health. However, as shown in this section, solar energy systems may contain small amounts of toxic materials, but these materials do not endanger public health. To understand potential toxic hazards coming from a solar project, one must understand system installation, materials used, the panel end-of-life protocols, and system operation. This section will examine these aspects of a solar farm and the potential for toxicity impacts in the following subsections:

(1.2) Project Installation/Construction
(1.2) System Components
  1.2.1 Solar Panels: Construction and Durability
  1.2.2 Photovoltaic technologies
    (a) Crystalline Silicon
    (b) Cadmium Telluride (CdTe)
    (c) CIS/CIGS
  1.2.3 Panel End of Life Management
  1.2.4 Non-panel System Components
(1.3) Operations and Maintenance

1.1 Project Installation/ Construction

The system installation, or construction, process does not require toxic chemicals or processes. The site is mechanically cleared of large vegetation, fences are constructed, and the land is surveyed to layout exact installation locations. Trenches for underground wiring are dug and support posts are driven into the ground. The solar panels are bolted to steel and aluminum support structures and wired together. Inverter pads are installed, and an inverter and transformer are installed on each pad. Once everything is connected, the system is tested, and only then turned on.

Figure 1: Utility-scale solar facility (5 MWAC) located in Catawba County. *Source: Strata Solar*

1.2 • System Components

1.2.1 Solar Panels: Construction and Durability

Solar PV panels typically consist of glass, polymer, aluminum, copper, and semiconductor materials that can be recovered and recycled at the end of their useful life.[2] Today there are two PV technologies used in PV panels at utility-scale solar facilities, silicon, and thin film. As of 2016, all thin film used in North Carolina solar facilities are cadmium telluride (CdTe) panels from the US manufacturer First Solar, but there are other thin film PV panels available on the market, such as Solar Frontier's CIGS panels. Crystalline silicon technology consists of silicon wafers which are made into cells and assembled into panels, thin film technologies consist of thin layers of semiconductor material deposited onto glass, polymer or metal substrates. While there are differences in the components and manufacturing processes of these two types of solar technologies, many aspects of their PV panel construction are very similar. Specifics about each type of PV chemistry as it relates to toxicity are covered in subsections a, b, and c in section 1.2.2; on crystalline silicon, cadmium telluride, and CIS/CIGS respectively. The rest of this section applies equally to both silicon and thin film panels.

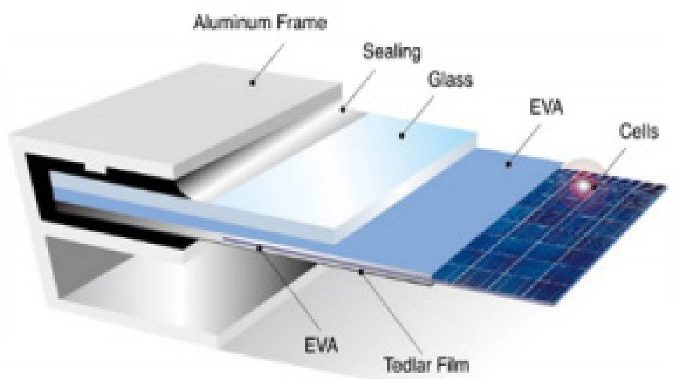


Figure 2: Components of crystalline silicon panels. The vast majority of silicon panels consist of a glass sheet on the topside with an aluminum frame providing structural support. Image Source: www.riteksolar.com.tw

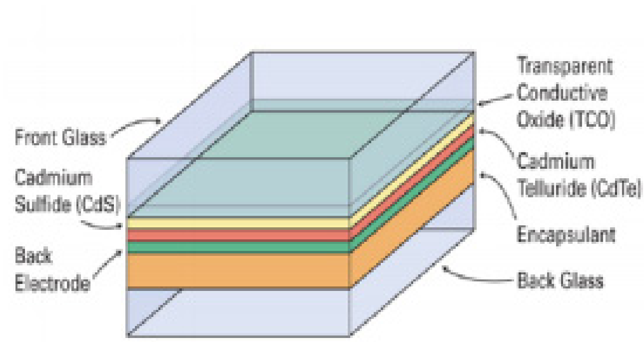


Figure 3: Layers of a common frameless thin-film panel (CdTe). Many thin film panels are frameless, including the most common thin-film panels, First Solar's CdTe. Frameless panels have protective glass on both the front and back of the panel. Layer thicknesses not to scale. Image Source: www.homepower.com

To provide decades of corrosion-free operation, PV cells in PV panels are encapsulated from air and moisture between two layers of plastic. The encapsulation layers are protected on the top with a layer of tempered glass and on the backside with a polymer sheet. Frameless modules include a protective layer of glass on the rear of the panel, which may also be tempered. The plastic ethylene-vinyl acetate (EVA) commonly provides the cell encapsulation. For decades, this same material has been used between layers of tempered glass to give car windshields and hurricane windows their great strength. In the same way that a car windshield cracks but stays intact, the EVA layers in PV panels keep broken panels intact (see Figure 4). Thus, a damaged module does not generally create small pieces of debris; instead, it largely remains together as one piece.

Figure 4: The mangled PV panels in this picture illustrate the nature of broken solar panels; the glass cracks but the panel is still in one piece. Image Source: http://img.alibaba.com/photo/115259576/broken_solar_panel.jpg

PV panels constructed with the same basic components as modern panels have been installed across the globe for well over thirty years.[3] The long-term durability and performance demonstrated over these decades, as well as the results of accelerated lifetime testing, helped lead to an industrystandard 25-year power production warranty for PV panels. These power warranties warrant a PV panel to produce at least 80% of their original nameplate production after 25 years of use. A recent SolarCity and DNV GL study reported that today's quality PV panels should be expected to reliably and efficiently produce power for thirty-five years.[4]

Local building codes require all structures, including ground mounted solar arrays, to be engineered to withstand anticipated wind speeds, as defined by the local wind speed requirements. Many racking products are available in versions engineered for wind speeds of up to 150 miles per hour, which is significantly higher than the wind speed requirement anywhere in North Carolina. The strength of PV mounting structures were demonstrated during Hurricane Sandy in 2012 and again during Hurricane Matthew in 2016. During Hurricane Sandy, the many large-scale solar facilities in New Jersey and New York at that time suffered only minor damage.[5] In the fall of 2016, the US and Caribbean experienced destructive winds and torrential rains from Hurricane Matthew, yet one leading solar tracker manufacturer reported that their numerous systems in the impacted area received zero damage from wind or flooding.[6]

In the event of a catastrophic event capable of damaging solar equipment, such as a tornado, the system will almost certainly have property insurance that will cover the cost to cleanup and repair the project. It is in the best interest of the system owner to protect their investment against such risks. It is also in their interest to get the project repaired and producing full power as soon as possible. Therefore, the investment in adequate insurance is a wise business practice for the system owner. For the same reasons, adequate insurance coverage is also generally a requirement of the bank or firm providing financing for the project.

1.2.2 Photovoltaic (PV) Technologies

a. Crystalline Silicon

This subsection explores the toxicity of silicon-based PV panels and concludes that they do not pose a material risk of toxicity to public health and safety. Modern crystalline silicon PV panels, which account for over 90% of solar PV panels installed today, are, more or less, a commodity product. The overwhelming majority of panels installed in North Carolina are crystalline silicon panels that are informally classified as Tier I panels. Tier I panels are from well-respected manufacturers that have a good chance of being able to honor warranty claims. Tier I panels are understood to be of high quality, with predictable performance, durability, and content. Well over 80% (by weight) of the content of a PV panel is the tempered glass front and the aluminum frame, both of which are common building materials. Most of the remaining portion are common plastics, including polyethylene terephthalate in the backsheet, EVA encapsulation of the PV cells, polyphenyl ether in the junction box, and polyethylene insulation on the wire leads. The active, working components of the system are the silicon photovoltaic cells, the small electrical leads connecting them together, and to the wires coming out of the back of the panel. The electricity generating and conducting components makeup less than 5% of the weight of most panels. The PV cell itself is nearly 100% silicon, and silicon is the second most common element in the Earth's crust. The silicon for PV cells is obtained by high-temperature processing of quartz sand (SiO2) that removes its oxygen molecules. The refined silicon is converted to a PV cell by adding extremely small amounts of boron and phosphorus, both of which are common and of very low toxicity.

The other minor components of the PV cell are also generally benign; however, some contain lead, which is a human toxicant that is particularly harmful to young children. The minor components include an extremely thin antireflective coating (silicon nitride or titanium dioxide), a thin layer of aluminum on the rear, and thin strips of silver alloy that are screen-printed on the front and rear of cell.[7] In order for the front and rear electrodes to make effective electrical contact with the proper layer of the PV cell, other materials (called glass frit) are mixed with the silver alloy and then heated to etch the metals into the cell. This glass frit historically contains a small amount of lead (Pb) in the form of lead oxide. The 60 or 72 PV cells in a PV panel are connected by soldering thin solder-covered copper tabs from the back of one cell to the front of the next cell. Traditionally a tin-based solder containing some lead (Pb) is used, but some manufacturers have switched to lead-free solder. The glass frit and/or the solder may contain trace amounts of other metals, potentially including some with human toxicity such as cadmium. However, testing to simulate the potential for leaching from broken panels, which is discussed in more detail below, did not find a potential toxicity threat from these trace elements. Therefore, the tiny amount of lead in the grass frit and the solder is the only part of silicon PV panels with a potential to create a negative health impact. However, as described below, the very limited amount of lead involved and its strong physical and chemical attachment to other components of the PV panel means that even in worst-case scenarios the health hazard it poses is insignificant.

As with many electronic industries, the solder in silicon PV panels has historically been a leadbased solder, often 36% lead, due to the superior properties of such solder. However, recent advances in lead-free solders have spurred a trend among PV panel manufacturers to reduce or remove the lead in their panels. According to the 2015 Solar Scorecard from the Silicon Valley Toxics Coalition, a group that tracks environmental responsibility of photovoltaic panel manufacturers, fourteen companies (increased from twelve companies in 2014) manufacture PV panels certified to meet the European Restriction of Hazardous Substances (RoHS) standard. This means that the amount of cadmium and lead in the panels they manufacture fall below the RoHS thresholds, which are set by the European Union and serve as the world's de facto standard for hazardous substances in manufactured goods.[8] The Restriction of Hazardous Substances (RoHS) standard requires that the maximum concentration found in any homogenous material in a produce is less than 0.01% cadmium and less than 0.10% lead, therefore, any solder can be no more than 0.10% lead.[9]

While some manufacturers are producing PV panels that meet the RoHS standard, there is no requirement that they do so because the RoHS Directive explicitly states that the directive does not apply to photovoltaic panels.[10] The justification for this is provided in item 17 of the current RoHS Directive: "The development of renewable forms of energy is one of the Union's key objectives, and the contribution made by renewable energy sources to environmental and climate objectives is crucial. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources (4) recalls that there should be coherence between those objectives and other Union environmental legislation. Consequently, this Directive should not prevent the development of renewable energy technologies that have no negative impact on health and the environment and that are sustainable and economically viable."

The use of lead is common in our modern economy. However, only about 0.5% of the annual lead consumption in the U.S. is for electronic solder for all uses; PV solder makes up only a tiny portion of this 0.5%. Close to 90% of lead consumption in the US is in batteries, which do not encapsulate the pounds of lead contained in each typical automotive battery. This puts the lead in batteries at great risk of leaching into the environment. Estimates for the lead in a single PV panel with lead-based solder range from 1.6 to 24 grams of lead, with 13g (less than half of an ounce) per panel seen most often in the literature.[11] At 13 g/panel[12], each panel contains one-half of the lead in a typical 12-gauge shotgun shell. This amount equates to roughly 1/750th of the lead in a single car battery. In a panel, it is all durably encapsulated from air or water for the full life of the panel.[14]

As indicated by their 20 to 30-year power warranty, PV modules are designed for a long service life, generally over 25 years. For a panel to comply with its 25-year power warranty, its internal components, including lead, must be sealed from any moisture. Otherwise, they would corrode and the panel's output would fall below power warranty levels. Thus, the lead in operating PV modules is not at risk of release to the environment during their service lifetime. In extreme experiments, researchers have shown that lead can leach from crushed or pulverized panels.[15, 16] However, more real-world tests designed to represent typical trash compaction that are used to classify waste as hazardous or non-hazardous show no danger from leaching.[17,18] For more information about PV panel end-of-life, see the Panel Disposal section.

As illustrated throughout this section, silicon-based PV panels do not pose a material threat to public health and safety. The only aspect of the panels with potential toxicity concerns is the very small amount of lead in some panels. However, any lead in a panel is well sealed from environmental exposure for the operating lifetime of the solar panel and thus not at risk of release into the environment.

b. Cadmium Telluride (CdTe) PV Panels

This subsection examines the components of a cadmium telluride (CdTe) PV panel. Research demonstrates that they pose negligible toxicity risk to public health and safety while significantly reducing the public's exposure to cadmium by reducing coal emissions. As of mid-2016, a few hundred MWs of cadmium telluride (CdTe) panels, all manufactured by the U.S. company First Solar, have been installed in North Carolina.

Questions about the potential health and environmental impacts from the use of this PV technology are related to the concern that these panels contain cadmium, a toxic heavy metal. However, scientific studies have shown that cadmium telluride differs from cadmium due to its high chemical and thermal stability.[19] Research has shown that the tiny amount of cadmium in these panels does not pose a health or safety risk.[20] Further, there are very compelling reasons to welcome its adoption due to reductions in unhealthy pollution associated with burning coal. Every GWh of electricity generated by burning coal produces about 4 grams of cadmium air emissions.[21] Even though North Carolina produces a significant fraction of our electricity from coal, electricity from solar offsets much more natural gas than coal due to natural gas plants being able to adjust their rate of production more easily and quickly. If solar electricity offsets 90% natural gas and 10% coal, each 5-megawatt (5 MWAC, which is generally 7 MWDC) CdTe solar facility in North Carolina keeps about 157 grams, or about a third of a pound, of cadmium *out* of our environment.[22, 23]

Cadmium is toxic, but all the approximately 7 grams of cadmium in one CdTe panel is in the form of a chemical compound cadmium telluride,[24] which has 1/100th the toxicity of free cadmium.[25] Cadmium telluride is a very stable compound that is non-volatile and non-soluble in water. Even in the case of a fire, research shows that less than 0.1% of the cadmium is released when a CdTe panel is exposed to fire. The fire melts the glass and encapsulates over 99.9% of the cadmium in the molten glass.[27]

It is important to understand the source of the cadmium used to manufacture CdTe PV panels. The cadmium is a byproduct of zinc and lead refining. The element is collected from emissions and waste streams during the production of these metals and combined with tellurium to create the CdTe used in PV panels. If the cadmium were not collected for use in the PV panels or other products, it would otherwise either be stockpiled for future use, cemented and buried, or disposed of.[28] Nearly all the cadmium in old or broken panels can be recycled which can eventually serve as the primary source of cadmium for new PV panels.[29]

Similar to silicon-based PV panels, CdTe panels are constructed of a tempered glass front, one instead of two clear plastic encapsulation layers, and a rear heat strengthened glass backing (together >98% by weight). The final product is built to withstand exposure to the elements without significant damage for over 25 years. While not representative of damage that may occur in the field or even at a landfill, laboratory evidence has illustrated that when panels are ground into a fine powder, very acidic water is able to leach portions of the cadmium and tellurium,[30] similar to the process used to recycle CdTe panels. Like many silicon-based panels, CdTe panels are reported (as far back ask 1998[31] to pass the EPA's Toxic Characteristic Leaching Procedure (TCLP) test, which tests the potential for crushed panels in a landfill to leach hazardous substances into groundwater.[32] Passing this test means that they are classified as non-hazardous waste and can be deposited in landfills.[33,34] For more information about PV panel end-of-life, see the Panel Disposal section.

There is also concern of environmental impact resulting from potential catastrophic events involving CdTe PV panels. An analysis of worst-case scenarios for environmental impact from CdTe PV panels, including earthquakes, fires, and floods, was conducted by the University of Tokyo in 2013. After reviewing the extensive international body of research on CdTe PV technology, their report concluded, “Even in the worst-case scenarios, it is unlikely that the Cd concentrations in air and sea water will exceed the environmental regulation values.”[35] In a worst-case scenario of damaged panels abandoned on the ground, insignificant amounts of cadmium will leach from the panels. This is because this scenario is much less conducive (larger module pieces, less acidity) to leaching than the conditions of the EPA’s TCLP test used to simulate landfill conditions, which CdTe panels pass.[36]

First Solar, a U.S. company, and the only significant supplier of CdTe panels, has a robust panel take-back and recycling program that has been operating commercially since 2005.[37] The company states that it is “committed to providing a commercially attractive recycling solution for photovoltaic (PV) power plant and module owners to help them meet their module (end of life) EOL obligation simply, costeffectively and responsibly.” First Solar global recycling services to their customers to collect and recycle panels once they reach the end of productive life whether due to age or damage. These recycling service agreements are structured to be financially attractive to both First Solar and the solar panel owner. For First Solar, the contract provides the company with an affordable source of raw materials needed for new panels and presumably a diminished risk of undesired release of Cd. The contract also benefits the solar panel owner by allowing them to avoid tipping fees at a waste disposal site. The legal contract helps provide peace of mind by ensuring compliance by both parties when considering the continuing trend of rising disposal costs and increasing regulatory requirements.

c. CIS/CIGS and other PV technologies

Copper indium gallium selenide PV technology, often referred to as CIGS, is the second most common type of thin-film PV panel but a distant second behind CdTe. CIGS cells are composed of a thin layer of copper, indium, gallium, and selenium on a glass or plastic backing. None of these elements are very toxic, although selenium is a regulated metal under the Federal Resource Conservation and Recovery Act (RCRA).[38] The cells often also have an extremely thin layer of cadmium sulfide that contains a tiny amount of cadmium, which is toxic. The promise of high efficiency CIGS panels drove heavy investment in this technology in the past. However, researchers have struggled to transfer high efficiency success in the lab to low-cost full-scale panels in the field.[39] Recently, a CIGS manufacturer based in Japan, Solar Frontier, has achieved some market success with a rigid, glass-faced CIGS module that competes with silicon panels. Solar Frontier produces the majority of CIS panels on the market today.[40] Notably, these panels are RoHS compliant,[41] thus meeting the rigorous toxicity standard adopted by the European Union even thought this directive exempts PV panels. The authors are unaware of any completed or proposed utility-scale system in North Carolina using CIS/CIGS panels.

1.2.3 Panel End-of-Life Management

Concerns about the volume, disposal, toxicity, and recycling of PV panels are addressed in this subsection. To put the volume of PV waste into perspective, consider that by 2050, when PV systems installed in 2020 will reach the end of their lives, it is estimated that the global annual PV panel waste tonnage will be 10% of the 2014 global e-waste tonnage.[42] In the U.S., end-of-life disposal of solar products is governed by the Federal Resource Conservation and Recovery Act (RCRA), as well as state policies in some situations. RCRA separates waste into hazardous (not accepted at ordinary landfill) and solid waste (generally accepted at ordinary landfill) based on a series of rules. According to RCRA, the way to determine if a PV panel is classified as hazardous waste is the Toxic Characteristic Leaching Procedure (TCLP) test. This EPA test is designed to simulate landfill disposal and determine the risk of hazardous substances leaching out of the landfill.[43,44,45] Multiple sources report that most modern PV panels (both crystalline silicon and cadmium telluride) pass the TCLP test.[46,47] Some studies found that some older (1990s) crystalline silicon panels, and perhaps some newer crystalline silicon panels (specifics are not given about vintage of panels tested), do not pass the lead (Pb) leachate limits in the TCLP test.[48,49]

The test begins with the crushing of a panel into centimeter-sized pieces. The pieces are then mixed in an acid bath. After tumbling for eighteen hours, the fluid is tested for forty hazardous substances that all must be below specific threshold levels to pass the test. Research comparing TCLP conditions to conditions of damaged panels in the field found that simulated landfill conditions provide overly conservative estimates of leaching for field-damaged panels.[50] Additionally, research in Japan has found no detectable Cd leaching from cracked CdTe panels when exposed to simulated acid rain.[51]

Although modern panels can generally be landfilled, they can also be recycled. Even though recent waste volume has not been adequate to support significant PV-specific recycling infrastructure, the existing recycling industry in North Carolina reports that it recycles much of the current small volume of broken PV panels. In an informal survey conducted by the NC Clean Energy Technology Center survey in early 2016, seven of the eight large active North Carolina utility-scale solar developers surveyed reported that they send damaged panels back to the manufacturer and/or to a local recycler. Only one developer reported sending damaged panels to the landfill. The developers reported at that time that they are usually paid a small amount per panel by local recycling firms. In early 2017, a PV developer reported that a local recycler was charging a small fee per panel to recycle damaged PV panels. The local recycling firm known to authors to accept PV panels described their current PV panel recycling practice as of early 2016 as removing the aluminum frame for local recycling and removing the wire leads for local copper recycling. The remainder of the panel is sent to a facility for processing the non-metallic portions of crushed vehicles, referred to as “fluff” in the recycling industry.[52] This processing within existing general recycling plants allows for significant material recovery of major components, including glass which is 80% of the module weight, but at lower yields than PV-specific recycling plants. Notably almost half of the material value in a PV panel is in the few grams of silver contained in almost every PV panel produced today. In the long-term, dedicated PV panel recycling plants can increase treatment capacities and maximize revenues resulting in better output quality and the ability to recover a greater fraction of the useful materials.[53] PV-specific panel recycling technologies have been researched and implemented to some extent for the past decade, and have been shown to be able to recover over 95% of PV material (semiconductor) and over 90% of the glass in a PV panel.[54]

A look at global PV recycling trends hints at the future possibilities of the practice in our country. Europe installed MW-scale volumes of PV years before the U.S. In 2007, a public-private partnership between the European Union and the solar industry set up a voluntary collection and recycling system called PV CYCLE. This arrangement was later made mandatory under the EU’s WEEE directive, a program for waste electrical and electronic equipment.[55] Its member companies (PV panel producers) fully finance the association. This makes it possible for end-users to return the member companies’ defective panels for recycling at any of the over 300 collection points around

Europe without added costs. Additionally, PV CYCLE will pick up batches of 40 or more used panels at no cost to the user. This arrangement has been very successful, collecting and recycling over 13,000 tons by the end of 2015.[56]

In 2012, the WEEE Directive added the end-of-life collection and recycling of PV panels to its scope.[57] This directive is based on the principle of extended-producer-responsibility. It has a global impact because producers that want to sell into the EU market are legally responsible for end-of-life management. Starting in 2018, this directive targets that 85% of PV products "put in the market" in Europe are recovered and 80% is prepared for reuse and recycling.

The success of the PV panel collection and recycling practices in Europe provides promise for the future of recycling in the U.S. In mid-2016, the US Solar Energy Industry Association (SEIA) announced that they are starting a national solar panel recycling program with the guidance and support of many leading PV panel producers.[58] The program will aggregate the services offered by recycling vendors and PV manufacturers, which will make it easier for consumers to select a cost-effective and environmentally responsible end-of-life management solution for their PV products. According to SEIA, they are planning the program in an effort to make the entire industry landfill-free. In addition to the national recycling network program, the program will provide a portal for system owners and consumers with information on how to responsibly recycle their PV systems.

While a cautious approach toward the potential for negative environmental and/or health impacts from retired PV panels is fully warranted, this section has shown that the positive health impacts of reduced emissions from fossil fuel combustion from PV systems more than outweighs any potential risk. Testing shows that silicon and CdTe panels are both safe to dispose of in landfills, and are also safe in worst case conditions of abandonment or damage in a disaster. Additionally, analysis by local engineers has found that the current salvage value of the equipment in a utility scale PV facility generally exceeds general contractor estimates for the cost to remove the entire PV system.[59,60,61]

1.2.4 Non-Panel System Components

(racking, wiring, inverter, transformer)

While previous toxicity subsections discussed PV panels, this subsection describes the non-panel components of utility-scale PV systems and investigates any potential public health and safety concerns. The most significant non-panel component of a ground-mounted PV system is the mounting structure of the rows of panels, commonly referred to as "racking". The vertical post portion of the racking is galvanized steel and the remaining above-ground racking components are either galvanized steel or aluminum, which are both extremely common and benign building materials. The inverters that make the solar generated electricity ready to send to the grid have weather-proof steel enclosures that protect the working components from the elements. The only fluids that they might contain are associated with their cooling systems, which are not unlike the cooling system in a computer. Many inverters today are RoHS compliant.

The electrical transformers (to boost the inverter output voltage to the voltage of the utility connection point) do contain a liquid cooling oil. However, the fluid used for that function is either a nontoxic mineral oil or a biodegradable non-toxic vegetable oil, such as BIOTEMP from ABB. These vegetable transformer oils have the additional advantage of being much less flammable than traditional mineral oils. Significant health hazards are associated with old transformers containing cooling oil with toxic PCBs. Transfers with PCB-containing oil were common before PCBs were outlawed in the U.S. in 1979. PCBs still exist in older transformers in the field across the country.

Other than a few utility research sites, there are no batteries on- or off-site associated with utility-scale solar energy facilities in North Carolina, avoiding any potential health or safety concerns related to battery technologies. However, as battery technologies continue to improve and prices continue to decline we are likely to start seeing some batteries at solar facilities. Lithium ion batteries currently dominate the world utility-scale battery market, which are not very toxic. No non-panel system components were found to pose any health or environmental dangers.

1.4 Operations and Maintenance – Panel Washing and Vegetation Control

Throughout the eastern U.S., the climate provides frequent and heavy enough rain to keep panels adequately clean. This dependable weather pattern eliminates the need to wash the panels on a regular basis. Some system owners may choose to wash panels as often as once a year to increase production, but most in N.C. do not regularly wash any PV panels. Dirt build up over time may justify panel washing a few times over the panels' lifetime; however, nothing more than soap and water are required for this activity.

The maintenance of ground-mounted PV facilities requires that vegetation be kept low, both for aesthetics and to avoid shading of the PV panels. Several approaches are used to maintain vegetation at NC solar facilities, including planting of limited-height species, mowing, weed-eating, herbicides, and grazing livestock (sheep). The following descriptions of vegetation maintenance practices are based on interviews with several solar developers as well as with three maintenance firms that together are contracted to maintain well over 100 of the solar facilities in N.C. The majority of solar facilities in North Carolina maintain vegetation primarily by mowing. Each row of panels has a single row of supports, allowing sickle mowers to mow under the panels. The sites usually require mowing about once a month during the growing season. Some sites employ sheep to graze the site, which greatly reduces the human effort required to maintain the vegetation and produces high quality lamb meat.[62]

In addition to mowing and weed eating, solar facilities often use some herbicides. Solar facilities generally do not spray herbicides over the entire acreage; rather they apply them only in strategic locations such as at the base of the perimeter fence, around exterior vegetative buffer, on interior dirt roads, and near the panel support posts. Also unlike many row crop operations, solar facilities generally use only general use herbicides, which are available over the counter, as opposed to restricted use herbicides commonly used in commercial agriculture that require a special restricted use license. The herbicides used at solar facilities are primarily 2-4-D and glyphosate (Round-up®), which are two of the most common herbicides used in lawns, parks, and agriculture across the country. One maintenance firm that was interviewed sprays the grass with a class of herbicide known as a growth regulator in order to slow the growth of grass so that mowing is only required twice a year. Growth regulators are commonly used on highway roadsides and golf courses for the same purpose. A commercial pesticide applicator license is required for anyone other than the landowner to apply herbicides, which helps ensure that all applicators are adequately educated about proper herbicide use and application. The license must be renewed annually and requires passing of a certification exam appropriate to the area in which the applicator wishes to work. Based on the limited data available, it appears that solar facilities in N.C. generally use significantly less herbicides per acre than most commercial agriculture or lawn maintenance services.

2. Electromagnetic Fields (EMF)

PV systems do not emit any material during their operation; however, they do generate electromagnetic fields (EMF), sometimes referred to as radiation. EMF produced by electricity is non-ionizing radiation, meaning the radiation has enough energy to move atoms in a molecule around (experienced as heat), but not enough energy to remove electrons from an atom or molecule (ionize) or to damage DNA. As shown below, modern humans are all exposed to EMF throughout our daily lives without negative health impact. Someone outside of the fenced perimeter of a solar facility is not exposed to significant EMF from the solar facility. Therefore, there is no negative health impact from the EMF produced in a solar farm. The following paragraphs provide some additional background and detail to support this conclusion.

Since the 1970s, some have expressed concern over potential health consequences of EMF from electricity, but no studies have ever shown this EMF to cause health problems.[63] These concerns are based on some epidemiological studies that found a slight increase in childhood leukemia associated with average exposure to residential power-frequency magnetic fields above 0.3 to 0.4 μT (microteslas) (equal to 3.0 to 4.0 mG (milligauss)). μT and mG are both units used to measure magnetic field strength. For comparison, the average exposure for people in the U.S. is one mG or 0.1 μT, with about 1% of the population with an average exposure in excess of 0.4 μT (or 4 mG).[64] These epidemiological studies, which found an association but not a causal relationship, led the World Health Organization's International Agency for Research on Cancer (IARC) to classify ELF magnetic fields as "possibly carcinogenic to humans". Coffee also has this classification. This classification means there is limited evidence but not enough evidence to designate as either a "probable carcinogen" or "human carcinogen". Overall, there is very little concern that ELF EMF damages public health. The only concern that does exist is for long-term exposure above 0.4 μT (4 mG) that may have some connection to increased cases of childhood leukemia. In 1997, the National Academies of Science were directed by Congress to examine this concern and concluded:

"Based on a comprehensive evaluation of published studies relating to the effects of power-frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human-health hazard. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects."[65]

There are two aspects to electromagnetic fields, an electric field and a magnetic field. The electric field is generated by voltage and the magnetic field is generated by electric current, i.e., moving electrons. A task group of scientific experts convened by the World Health Organization (WHO) in 2005 concluded that there were no substantive health issues related to electric fields (0 to 100,000 Hz) at levels generally encountered by members of the public.[66] The relatively low voltages in a solar facility and the fact that electric fields are easily shielded (i.e., blocked) by common materials, such as plastic, metal, or soil means that there is no concern of negative health impacts from the electric fields generated by a solar facility. Thus, the remainder of this section addresses magnetic fields. Magnetic fields are not shielded by most common materials and thus can easily pass through them. Both types of fields are strongest close to the source of electric generation and weaken quickly with distance from the source.

The direct current (DC) electricity produced by PV panels produce stationary (0 Hz) electric and magnetic fields. Because of minimal concern about potential risks of stationary fields, little scientific research has examined stationary fields' impact on human health.[67] In even the largest PV facilities, the DC voltages and currents are not very high. One can illustrate the weakness of the EMF generated by a PV panel by placing a compass on an operating solar panel and observing that the needle still points north.

While the electricity throughout the majority of a solar site is DC electricity, the inverters convert this DC electricity to alternating current (AC) electricity matching the 60 Hz frequency of the grid. Therefore, the inverters and the wires delivering this power to the grid are producing non-stationary EMF, known as extremely low frequency (ELF) EMF, normally oscillating with a frequency of 60 Hz. This frequency is at the low-energy end of the electromagnetic spectrum. Therefore, it has less energy than other commonly encountered types of non-ionizing radiation like radio waves, infrared radiation, and visible light.

The wide use of electricity results in background levels of ELF EMFs in nearly all locations where people spend time – homes, workplaces, schools, cars, the supermarket, etc. A person's average exposure depends upon the sources they encounter, how close they are to them, and the amount of time they spend there.[68] As stated above, the average exposure to magnetic fields in the U.S. is estimated to be around one mG or 0.1 μT, but can vary considerably depending on a person's exposure to EMF from electrical devices and wiring.[69] At times we are often exposed to much higher ELF magnetic fields, for example when standing three feet from a refrigerator the ELF magnetic field is 6 mG and when standing three feet from a microwave oven the field is about 50 mG.[70] The strength of these fields diminish quickly with distance from the source, but when surrounded by electricity in our homes and other buildings moving away from one source moves you closer to another. However, unless you are inside of the fence at a utility-scale solar facility or electrical substation it is impossible to get very close to the EMF sources. Because of this, EMF levels at the fence of electrical substations containing high voltages and currents are considered "generally negligible".[71,72]

The strength of ELF-EMF present at the perimeter of a solar facility or near a PV system in a commercial or residential building is significantly lower than the typical American's average EMF exposure.[73,74] Researchers in Massachusetts measured magnetic fields at PV projects and found the magnetic fields dropped to very low levels of 0.5 mG or less, and in many cases to less than background levels (0.2 mG), at distances of no more than nine feet from the residential inverters and 150 feet from the utility-scale inverters.[75] Even when measured within a few feet of the utility-scale inverter, the ELF magnetic fields were well below the International Commission on Non-Ionizing Radiation Protection's recommended magnetic field level exposure limit for the general public of 2,000 mG.[76] It is typical that utility scale designs locate large inverters central to the PV panels that feed them because this minimizes the length of wire required and shields neighbors from the sound of the inverter's cooling fans. Thus, it is rare for a large PV inverter to be within 150 feet of the project's security fence.

Anyone relying on a medical device such as pacemaker or other implanted device to maintain proper heart rhythm may have concern about the potential for a solar project to interfere with the operation of his or her device. However, there is no reason for concern because the EMF outside of the solar facility's fence is less than 1/1000 of the level at which manufacturers test for ELF EMF interference, which is 1,000 mG.[77] Manufacturers of potentially affected implanted devices often provide advice on electromagnetic interference that includes avoiding letting the implanted device get too close to certain sources of fields such as some household appliances, some walkie-talkies, and similar transmitting devices. Some manufacturers' literature does not mention high-voltage power lines, some say that exposure in public areas should not give interference, and some advise not spending extended periods of time close to power lines.[78]

3. Electric Shock and Arc Flash Hazards

There is a real danger of electric shock to anyone entering any of the electrical cabinets such as combiner boxes, disconnect switches, inverters, or transformers; or otherwise coming in contact with voltages over 50 Volts.[79] Another electrical hazard is an arc flash, which is an explosion of energy that can occur in a short circuit situation. This explosive release of energy causes a flash of heat and a shockwave, both of which can cause serious injury or death. Properly trained and equipped technicians and electricians know how to safely install, test, and repair PV systems, but there is always some risk of injury when hazardous voltages and/or currents are present. Untrained individuals should not attempt to inspect, test, or repair any aspect of a PV system due to the potential for injury or death due to electric shock and arc flash, The National Electric Code (NEC) requires appropriate levels of warning signs on all electrical components based on the level of danger determined by the voltages and current potentials. The national electric code also requires the site to be secured from unauthorized visitors with either a six-foot chain link fence with three strands of barbed wire or an eight-foot fence, both with adequate hazard warning signs.

4. Fire Safety

The possibility of fires resulting from or intensified by PV systems may trigger concern among the general public as well as among firefighters. However, concern over solar fire hazards should be limited because only a small portion of materials in the panels are flammable, and those components cannot self-support a significant fire. Flammable components of PV panels include the thin layers of polymer encapsulates surrounding the PV cells, polymer backsheets (framed panels only), plastic junction boxes on rear of panel, and insulation on wiring. The rest of the panel is composed of non-flammable components, notably including one or two layers of protective glass that make up over three quarters of the panel's weight.

Heat from a small flame is not adequate to ignite a PV panel, but heat from a more intense fire or energy from an electrical fault can ignite a PV panel.[80] One real-world example of this occurred during July 2015 in an arid area of California. Three acres of grass under a thin film PV facility burned without igniting the panels mounted on fixed-tilt racks just above the grass.[81] While it is possible for electrical faults in PV systems on homes or commercial buildings to start a fire, this is extremely rare.[82] Improving understanding of the PV-specific risks, safer system designs, and updated fire-related codes and standards will continue to reduce the risk of fire caused by PV systems.

PV systems on buildings can affect firefighters in two primary ways, 1) impact their methods of fighting the fire, and 2) pose safety hazard to the firefighters. One of the most important techniques that firefighters use to suppress fire is ventilation of a building's roof. This technique allows superheated toxic gases to quickly exit the building. By doing so, the firefighters gain easier and safer access to the building, Ventilation of the roof also makes the challenge of putting out the fire easier. However, the placement of rooftop PV panels may interfere with ventilating the roof by limiting access to desired venting locations.

New solar-specific building code requirements are working to minimize these concerns. Also, the latest National Electric Code has added requirements that make it easier for first responders to safely and effectively turn off a PV system. Concern for firefighting a building with PV can be reduced with proper fire fighter training, system design, and installation. Numerous organizations have studied fire fighter safety related to PV. Many organizations have published valuable guides and training programs. Some notable examples are listed below.

- The International Association of Fire Fighters (IAFF) and International Renewable Energy Council (IREC) partnered to create an online training course that is far beyond the PowerPoint click-andview model. The self-paced online course, "Solar PV Safety for Fire Fighters," features rich video content and simulated environments so fire fighters can practice the knowledge they've learned. www.iaff.org/pvsafetytraining
- Photovoltaic Systems and the Fire Code: Office of NC Fire Marshal
- Fire Service Training, Underwriter's Laboratory
- Firefighter Safety and Response for Solar Power Systems, National Fire Protection Research Foundation
- Bridging the Gap: Fire Safety & Green Buildings, National Association of State Fire Marshalls
- Guidelines for Fire Safety Elements of Solar Photovoltaic Systems, Orange County Fire Chiefs Association
- Solar Photovoltaic Installation Guidelines, California Department of Forestry & Fire Protection, Office of the State Fire Marshall
- PV Safety & Firefighting, Matthew Paiss, Homepower Magazine
- PV Safety and Code Development: Matthew Paiss, Cooperative Research Network

Summary

The purpose of this paper is to address and alleviate concerns of public health and safety for utility-scale solar PV projects. Concerns of public health and safety were divided and discussed in the four following sections: (1) Toxicity, (2) Electromagnetic Fields, (3) Electric Shock and Arc Flash, and (4) Fire. In each of these sections, the negative health and safety impacts of utility-scale PV development were shown to be negligible, while the public health and safety benefits of installing these facilities are significant and far outweigh any negative impacts.

---

1 Wiser, Ryan, Trieu Mai, Dev Millstein, Jordan Macknick, Alberta Carpenter, Stuart Cohen, Wesley Cole, Bethany Frew, and Garvin A. Heath. 2016. On the Path to SunShot: The Environmental and Public Health Benefits of Achieving High Penetrations of Solar Energy in the United States. Golden, CO: National Renewable Energy Laboratory. Accessed March 2017, www.nrel.gov/docs/fy16osti/65628.pdf

2 IRENA and IEA-PVPS (2016), "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems.

3 National Renewable Energy Laboratory, *Overview of Field Experience – Degradation Rates & Lifetimes*. September 14, 2015. Solar Power International Conference. Accessed March 2017, www.nrel.gov/docs/fy15osti/65040.pdf

4 Miesel et al. *SolarCity Photovoltaic Modules with 35 Year Useful Life*. June 2016. Accessed March 2017. http://www.solarcity.com/newsroom/reports/solarcity-photovoltaic-modules-35-year-useful-life

5 David Unger. *Are Renewables Stormproof? Hurricane Sandy Tests Solar, Wind*. November 2012. Accessed March 2017. http://www.csmonitor.com/Environment/Energy-Voices/2012/1119/Are-renewables-stormproof-Hurricane-Sandy-tests-solarwind & http://www.csmonitor.com/Environment/Energy-Voices/2012/1119/Are-renewables-stormproof-Hurricane-Sandytests-solar-wind

6 NEXTracker and 365 Pronto, *Tracking Your Solar Investment: Best Practices for Solar Tracker O&M*.

Accessed March 2017.
www.nextracker.com/content/uploads/2017/03/NEX-Tracker_OandM-WhitePaper_FINAL_March-2017.pdf
7 Christiana Honsberg, Stuart Bowden. *Overview of Screen Printed Solar Cells*. Accessed January 2017.
www.pveducation.org/pvcdrom/manufacturing/screen-printed
8 Silicon Valley Toxics Coalition. *2015 Solar Scorecard*. Accessed August 2016.
www.solarscorecard.com/2015/2015-SVTC-Solar-Scorecard.pdf
9 European Commission. *Recast of Reduction of Hazardous Substances (RoHS) Directive*. September 2016. Accessed August 2016.
http://ec.europa.eu/environment/waste/rohs_eee/index_en.htm
10 Official Journal of the European Union, *DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011* on the restriction of the use of certain hazardous substances in electrical and electronic equipment. June 2011. Accessed May 2017.
http://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32011L0065&from=en
11 Giancarlo Giacchetta, Mariella Leporini, Barbara Marchetti. *Evaluation of the Environmental Benefits of New High Value Process for the Management of the End of Life of Thin Film Photovoltaic Modules*. July 2013. Accessed August 2016.
www.researchgate.net/publication/257408804_Evaluation_of_the_environmental_benefits_of_new_high_value_process_for_the_management_of_the_end_of_life_of_thin_film_photovoltaic_modules
12 European Commission. *Study on Photovoltaic Panels Supplementing The Impact Assessment for a Recast of the Weee Directive*. April 2011. Accessed August 2016.
http://ec.europa.eu/environment/waste/weee/pdf/Study%20on%20PVs%20Bio%20final.pdf
14 The amount of lead in a typical car battery is 21.4 pounds. Waste 360. Chaz Miller. *Lead Acid Batteries*. March 2006. Accessed August 2016.
http://waste360.com/mag/waste_leadacid_batteries_3
15 Okkenhaug G. *Leaching from CdTe PV module material results from batch, column and availability tests*. Norwegian Geotechnical Institute, NGI report No. 20092155-00-6-R; 2010
16 International Journal of Advanced Applied Physics Research. Renate Zapf-Gottwick1, et al. *Leaching Hazardous Substances out of Photovoltaic Modules*. January 2015. Accessed January 2016.
www.cosmosscholars.com/phms/index.php/ijaapr/article/download/485/298
17 ibid
18 Parikhit Sinha, et al. Evaluation of Potential Health and Environmental Impacts from End-Of-Life Disposal of Photovoltaics, Photovoltaics, 2014. Accessed May 2016
19 Bonnet, D. and P. Meyers. 1998. *Cadmium-telluride—Material for thin film solar cells*. J. Mater. Res., Vol. 13, No. 10, pp. 2740-2753
20 V. Fthenakis, K. Zweibel. *CdTe PV: Real and Perceived EHS Risks*. National Center ofr Photovoltaics and Solar Program Review Meeting, March 24-26, 2003. www.nrel.gov/docs/fy03osti/33561.pdf. Accessed May 2017
21 International Energy Agency Photovoltaic Power Systems Programme. *Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems*. March 2015. Accessed August 2016.
http://iea-pvps.org/index.php?id=315
22 Data not available on fraction of various generation sources offset by solar generation in NC, but this is believed to be a reasonable rough estimate. The SunShot report entitled The Environmental and Public Health Benefits of Achieving High Penetrations of Solar Energy in the United States analysis contributes significant (% not provided) offsetting of coal-fired generation by solar PV energy in the southeast.
23 7 MWDC * 1.5 GWh/MWDC * 25 years * 0.93 degradation factor * (0.1 *4.65 grams/GWh + 0.9*0.2 grams/GWh)
24 Vasilis Fthenakis. *CdTe PV: Facts and Handy Comparisons*. January 2003. Accessed March 2017.
https://www.bnl.gov/pv/files/pdf/art_165.pdf
25 Kaczmar, S., *Evaluating the Read-Across Approach on CdTe Toxicity for CdTe Photovoltaics*, SETAC North America 32nd Annual Meeting, Boston, MA, November 2011. Available at:
ftp://ftp.co.imperial.ca.us/icpds/eir/campo-verdesolar/final/evaluating-toxicity.pdf, Accessed May 2017
27 V. M. Fthenakis et al, *Emissions and Encapsulation of Cadmium in CdTe PV Modules During Fires* Renewable Progress in Photovoltaics: Research and Application: Res. Appl. 2005; 13:1–11, Accessed March 2017, www.bnl.gov/pv/files/pdf/abs_179.pdf
28 Fthenakis V.M., *Life Cycle Impact Analysis of Cadmium in CdTe Photovoltaic Production*, Renewable

and Sustainable Energy Reviews, 8, 303-334, 2004. www.clca.columbia.edu/papers/Life_Cycle_Impact_Analysis_Cadmium_CdTe_Photovoltaic_production.pdf, Accessed May 2017
29 International Renewable Energy Agency. Stephanie Weckend, Andreas Wade, Garvin Heath. *End of Life Management: Solar Photovoltaic Panels*. June 2016. Accessed November 2016.
30 International Journal of Advanced Applied Physics Research. Renate Zapf-Gottwick1, et al. *Leaching Hazardous Substances out of Photovoltaic Modules*. January 2015. Accessed January 2016. www.cosmosscholars.com/phms/index.php/ijaapr/article/download/485/298
31 Cunningham D., Discussion about TCLP protocols, Photovoltaics and the Environment Workshop, July 23-24, 1998, Brookhaven National Laboratory, BNL-52557
32 Parikhit Sinha, et al. Evaluation of Potential Health and Environmental Impacts from End-Of-Life Disposal of Photovoltaics, Photovoltaics, 2014. Accessed May 2016
33 Practical Handbook of Photovoltaics: Fundamentals and Applications. T. Markvart and L. Castaner. *Chapter VII-2: Overview of Potential Hazards*. December 2003. Accessed August 2016. https://www.bnl.gov/pv/files/pdf/art_170.pdf
34 Norwegian Geotechnical Institute. *Environmental Risks Regarding the Use and End-of-Life Disposal of CdTe PV Modules*. April 2010. Accessed August 2016. https://www.dtsc.ca.gov/LawsRegsPolicies/upload/Norwegian-Geotechnical-InstituteStudy.pdf
35 First Solar. Dr. Yasunari Matsuno. December 2013. August 2016. *Environmental Risk Assessment of CdTe PV Systems to be considered under Catastrophic Events in Japan*. http://www.firstsolar.com/-/media/Documents/Sustainability/PeerReviews/Japan_Peer-Review_Matsuno_CdTe-PV-Tsunami.ashx
36 First Solar. Parikhit Sinha, Andreas Wade. *Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of PV Module Field Breakage*. 2015 IEEE
37 See p. 22 of First Solar, Sustainability Report. Available at: www.firstsolar.com/-/media/FirstSolar/Sustainability-Documents/03801_FirstSolar_SustainabilityReport_08MAR16_Web.ashx, Accessed May 2017
38 40 CFR §261.24. *Toxicity Characteristic*. May 2017. Accessed May 2017. https://www.ecfr.gov/cgi-bin/textidx-?node=se40.26.261_124&rgn=div8
39 Office of Energy Efficiency & Renewable Energy. *Copper Indium Gallium Diselenide*. Accessed March 2017. https://www.energy.gov/eere/sunshot/copper-indium-gallium-diselenide
40 Mathias Maehlum. *Best Thin Film Solar Panels – Amorphous, Cadmium Telluride or CIGS?* April 2015. Accessed March 2017. http://energyinformative.org/best-thin-film-solar-panels-amorphous-cadmium-telluride-cigs/
41 RoHS tested certificate for Solar Frontier PV modules. TUVRheinland, signed 11.11.2013
42 International Renewable Energy Agency. Stephanie Weckend, Andreas Wade, Garvin Heath. *End of Life Management: Solar Photovoltaic Panels.* June 2016. Accessed November 2016. http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf
43 40 C.F.R. §261.10. *Identifying the Characteristics of Hazardous Waste and for Listing Hazardous Waste*. November 2016. Accessed November 2016 http://www.ecfr.gov/cgi-bin/textidx?SID=ce0006d-66da40146b490084ca2816143&mc=true&node=pt40.26.261&rgn=div5#sp40.28.261.b
44 40 C.F.R. §261.24 *Toxicity Characteristic*. November 2016. Accessed November 2016. http://www.ecfr.gov/cgi-bin/textidx?SID=ce0006d-66da40146b490084ca2816143&mc=true&node=pt40.26.261&rgn=div5#se40.28.261_124
45 International Renewable Energy Agency. Stephanie Weckend, Andreas Wade, Garvin Heath. *End of Life Management: Solar Photovoltaic Panels*. June 2016. Accessed November 2016. http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf
46 TLCP test results from third-party laboratories for REC, Jinko, and Canadian Solar silicon-based panels. Provided by PV panel manufacturers directly or indirectly to authors
47 Sinovoltaics, Introduction to *Solar Panel Recycling*, March 2014. Accessed October 2016. http://sinovoltaics.com/solarbasics/introduction-to-solar-panel-recycling/
48 Brookhaven National Laboratory. Vasilis Fthenakis,

Regulations on Photovoltaic Module Disposal and Recycling. January 29, 2001.
49 Parikhit Sinha, et al. Evaluation of Potential Health and Environmental Impacts from End-Of-Life Disposal of Photovoltaics, Photovoltaics, 2014.
50 First Solar. Parikhit Sinha, Andreas Wade. *Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of PV Module Field Breakage*. October 2015. Accessed August 2016.
http://www.firstsolar.com/-/media/Documents/Sustainability/PVSC42-Manuscript-20150912--Assessment-of-Leaching-Tests-for-Evaluating-PotentialEnvironmental-Impa.ashx
51 First Solar. Dr. Yasunari Matsuno. December 2013. *Environmental Risk Assessment of CdTe PV Systems to be considered under Catastrophic Events in Japan*.
http://www.firstsolar.com/-/media/Documents/Sustainability/PeerReviews/Japan_Peer-Review_Matsuno_CdTe-PV-Tsunami.ashx
52 Phone interview, February 3, 2016, TT&E Iron & Metal, Garner, NC www.ncscrapmetal.com
53 Wen-His Huang, et al. *Strategy and Technology To Recycle Water-silicon Solar Modules*. Solar Energy, Volume 144, March 2017, Pages 22-31
54 International Renewable Energy Agency. Stephanie Weckend, Andreas Wade, Garvin Heath. *End of Life Management: Solar Photovoltaic Panels*. June 2016. Accessed November 2016.
http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf
55 Official Journal of the European Union. *Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment*. July 2012. Accessed November 2016.
http://eurlex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019
56 PV CYCLE. *Annual Report 2015*. Accessed November 2016.
https://pvcyclepublications.cld.bz/Annual-Report-PV-CYCLE-2015/6-7
57 Official Journal of the European Union. *Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment*. July 2012. Accessed November 2016.
http://eurlex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019
58 SEIA National PV Recycling Program:
www.seia.org/seia-national-pv-recycling-program
59 RBI Solar, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in June 2016. Accessed April 2017.
www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2015-05_DecommissioningPlan.pdf
60 Birdseye Renewables, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in May 2015. Accessed April 2017.
www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2015-04_DecommissioningPlan.pdf
61 Cypress Creek Renewables, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in September 2016. Accessed April 2017.
www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2016-06decommission.pdf
62 Sun Raised Farms:
http://sunraisedfarms.com/index.html
63 National Institute of Environmental Health Sciences and National Institutes of Health, EMF: Electric and Magnetic Fields Associated with Electric Power: Questions and Answers, June 2002
64 World Health Organization. *Electromagnetic Fields and Public Health: Exposure to Extremely Low Frequency Fields*. June 2007. Accessed August 2016.
http://www.who.int/peh-emf/publications/facts/fs322/en/
65 Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems, National Research Council, Possible Health Effects of Exposure to Residential Electric and Magnetic Fields, ISBN: 0-309-55671-6, 384 pages, 6 x 9, (1997) This PDF is available from the National Academies Press at:
http://www.nap.edu/catalog/5155.html
66 World Health Organization. *Electromagnetic Fields and Public Health: Exposure to Extremely Low Frequency Fields*. June 2007. Accessed August 2016.
http://www.who.int/peh-emf/publications/facts/fs322/en/
67 World Health Organization. *Electromagnetic Fields and Public Health: Static Electric and Magnetic Fields*. March 2006. Accessed August 2016.
http://www.who.int/peh-emf/publications/facts/fs299/en/
68 Asher Sheppard, Health Issues Related to the Static and Power-Frequency Electric and Magnetic Fields (EMFs) of the Soitec Solar Energy Farms, April

30, 2014. Accessed March 2017:
www.sandiegocounty.gov/content/dam/sdc/pds/ceqa/Soitec-Documents/Final-EIR-Files/Appendix_9.0-1_EMF.pdf

69 Massachusetts Clean Energy Center. *Study of Acoustic and EMF Levels from Solar Photovoltaic Projects*. December 2012. Accessed August 2016.

70 Duke Energy Corporation. *Frequently Asked Questions: Electric and Magnetic Fields*. Accessed August 2016.
https://www.duke-energy.com/about-energy/frequently_asked_questions.asp

71 National Institute of Environmental Health Sciences, *Electric and Magnetic Fields Associate with the use of Electric Power: Questions and Answers*, 2002. Accessed November 2016
www.niehs.nih.gov/health/materials/electric_and_magnetic_fields

72 Duke Energy Corporation. *Frequently Asked Questions: Electric and Magnetic Fields*. Accessed August 2016.
https://www.duke-energy.com/about-energy/frequently_asked_questions.asp

73 R.A. Tell et al, *Electromagnetic Fields Associated with Commercial Solar Photovoltaic Electric Power Generating Facilities*, Journal of Occupational and Environmental Hygiene, Volume 12, 2015,- Issue 11. Abstract Accessed March 2016:
http://www.tandfonline.com/doi/full/10.1080/15459624.2015.1047021

74 Massachusetts Department of Energy Resources, Massachusetts Department of Environmental Protection, and Massachusetts Clean Energy Center. *Questions & Answers: Ground-Mounted Solar Photovoltaic Systems*. June 2015. Accessed August 2016.
http://www.mass.gov/eea/docs/doer/renewables/solar/solar-pv-guide.pdf

75 Ibid.

76 Ibid.

77 *EMFs and medical devices*, Accessed March 2017.
www.emfs.info/effects/medical-devices/

78 ibid.

79 Damon McCluer. *Electrical Construction & Maintenance: NFPA 70E's Approach to Considering DC Hazards*. September 2013. Accessed October 2016.
http://ecmweb.com/safety/nfpa-70e-s-approach-considering-dc-hazards

80 Hong-Yun Yang, et. al. *Experimental Studies on the Flammability and Fire Hazards of Photovoltaic Modules, Materials*. July 2015. Accessed August 2016.
http://www.mdpi.com/1996-1944/8/7/4210/pdf

81 Matt Fountain. The Tribune. *Fire breaks out at Topaz Solar Farm*. July 2015. Accessed August 2016.
www.sanluisobispo.com/news/local/article39055539.html

82 Cooperative Research Network. Matthew Paiss. *Tech Surveillance: PV Safety & Code Developments*. October 2014. Accessed August 2016.
http://www.nreca.coop/wp-content/uploads/2013/06/ts_pv_fire_safety_oct_2014.pdf

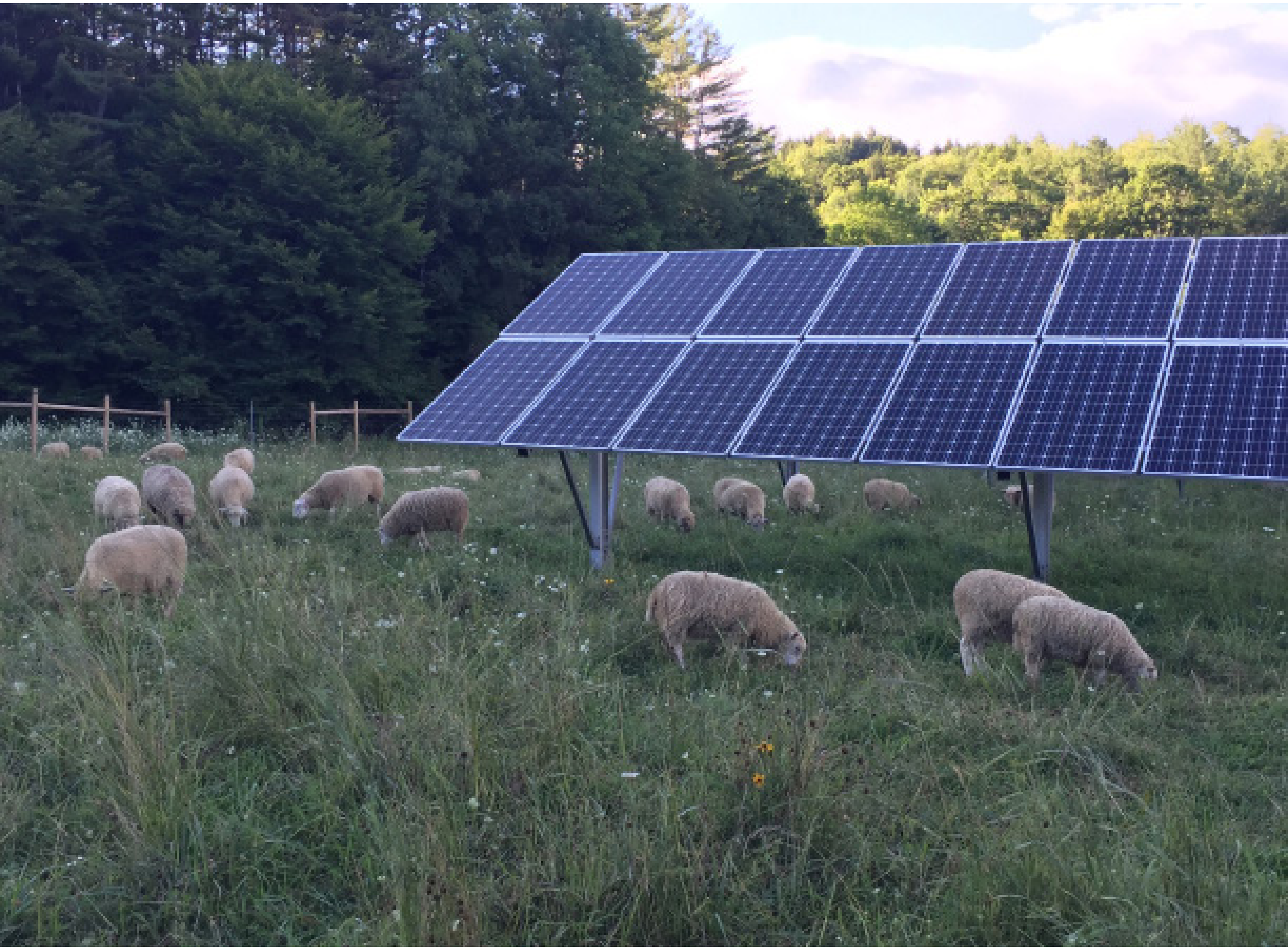
Exhibit B

Balancing Agricultural Productivity with Ground Based Solar Photovoltaic Development

WHITE PAPER

Balancing Agricultural Productivity with Ground-Based Solar Photovoltaic (PV) Development

Tommy Cleveland and David Sarkisian
May 2019



NC CLEAN ENERGY TECHNOLOGY CENTER

NC STATE UNIVERSITY

Contents

Balancing Agricultural Productivity with Ground-Based Solar Photovoltaic (PV) Development

Introduction

For centuries North Carolina farmers have made a major contribution to the state's economy by working the land and providing billions of pounds of agricultural and forestry products to meet demands for food and fiber. This resource serves as a foundational economic building block for the state. North Carolina's farming and forestry community provides North Carolinians and people across the world with food and fiber. That said, the demands of our growing, modern society require renewable forms of energy to begin to replace finite non-renewable energy resources that have traditionally provided the means for transportation, electricity, and much more.

Given that land and climatic conditions suitable for agriculture are finite, solar development may compete with agricultural land use. One use converts sunlight and fertilizer into food and fiber, while the other converts sunlight into electricity. The purpose of this paper is to explore the extent to which solar photovoltaic facilities and agricultural production compete for land use, as well as the extent to which agricultural production is affected by solar development. The paper is divided into two sections:

(1) Understanding the Context of Solar Development and Agriculture in North Carolina.
- (1.1) Developing Renewable Energy,
- (1.2) Landowner Land Use Choice,
- (1.3) Solar Facility Construction,
- (1.4) Duration of Solar Use,

(2) Weighing the Impact of PV Development on Agriculture
- (2.1) Solar PV Land Use
- (2.2) Impact on Agricultural Productivity

1. Understanding the Context of Solar Development and Agriculture in NC

This section provides some background on solar development in North Carolina. By illustrating the existing demand for renewable energy (1.1), touching on the state's political climate towards private land use (1.2), and highlighting two important considerations of PV development (1.3 and 1.4), the context surrounding the two competing land uses of solar development and agriculture can be better understood. As agriculture is and has been a dominant, established land use in this state for generations, discussion in this section will primarily focus on the increasing demands of land to be used for solar development.

1.1 Developing Renewable Energy

Currently, almost all of North Carolina's electricity is generated from fuels, such as coal, natural gas, and uranium, which are produced outside the state. Some coal plants in North Carolina are reaching the end of their useful lives and being retired.[1,2] Alternative sources of energy, such as solar and wind, have become much more economically attractive in the last several years, making it possible to economically replace some nuclear, coal, and gas electricity generation with these sources.[3]

More than three hundred privately financed utility-scale solar facilities operate in North Carolina under current electricity prices, regulations, and policies, with more planned for the future. As with any new technology, price drops and performance improvements may be expected over time as production volumes increase and experience is gained. Since 2009, the total cost to develop and build a utility-scale solar facility in North Carolina has dropped from over $5 per watt to about $1 per watt. This rapid cost reduction in utility-scale solar facilities has greatly improved the financial viability of solar projects; many solar projects are now being planned even without the North Carolina renewable energy tax credit that expired at the end of 2015.[4,5]

In addition to the increasingly attractive economics, some of the shift towards solar energy has been driven by policy choices. Solar and other types of renewable energy have many benefits that have motivated support from policymakers. For instance, they do not use imported fuel, reducing our exposure to fuel price volatility. Solar energy also does not produce the air pollution and greenhouse gases emitted by fossil fuel-powered electricity generation, and it avoids some other environmental risks associated with fossil and nuclear fuels such as coal ash and radioactive waste disposal. Reduction of air pollution has been part of state and national policy for decades, and the U.S. has seen steadily improving air quality as a result[6] Solar and other clean energy sources assist in this ongoing reduction in air pollution.

Solar energy offers many benefits to North Carolina. However, while solar development provides a source of clean in-state energy, it requires land to do so. This means that solar energy projects will sometimes compete with other potential land uses.

1.2 Landowner Land Use Choice

North Carolina policy generally leaves land use decisions in the hands of landowners. That said, the state, local, and federal governments can encourage or discourage specific landowner choices through the incentives or disincentives that they provide for particular uses, as well as through various forms of regulation, such as zoning rules and environmental restrictions. The balance of state-provided incentives for agricultural or solar energy production can, in some cases, be the determining factor in the decision to invest in solar or agriculture development. Also, the current grid infrastructure limits the sites feasible for solar development; it is only feasible to connect solar to certain locations in the grid and only to a limited density.

North Carolina has granted local governments the power to regulate land use in their jurisdictions, although state and federal rules apply in many circumstances. This means that local governments can manage land development with the needs of the community in mind, while also safeguarding natural resources. These land-use regulations can put limits on the allowed uses for some land and thus limit landowners' options, in some cases affecting the viability of solar development. Some agricultural land has been exempted from certain regulations due to "grandfathering," and changing the land use to solar may remove these exemptions, which can affect the ability to return the land to agricultural use in the future.[7]

Land use regulations that may be relevant to solar development, depending on the location, can include (but are not limited to):[8]

- Local zoning and land use rules (fencing, buffer zones between buildings and roads, border shrubs/trees, etc.)
- Floodplain development rules

- Erosion and sedimentation rules
- Permitting regarding military and air traffic impact
- Water quality rules (i.e. Neuse nutrient strategy rules, Coastal Area Management Act rules)
- USDA wetlands impact rules

To determine whether these and other rules are relevant for a potential solar development, landowners and solar developers should consult their local government planning departments, the Soil and Water Conservation Division of the N.C. Department of Agriculture and Consumer Services, the USDA Natural Resources Conservation Service office, and the USDA Farm Services Agency.

1.3 Solar Facility Construction

Solar panels are supported by steel or aluminum racks. The racks are attached to galvanized steel posts driven 6-8 feet into the ground without concrete, although very occasionally, site conditions require the use of cement grout in the pile hole. The only concrete is generally at the inverter/transformer pads which are typically about 10’ by 20’ each. There is usually no more than one such pad per MW of AC capacity. At some sites these pads are precast concrete or steel skids that sit above grade on helical steel piers. Much of the wiring at the site is above-ground attached to the racking under the rows of panels. The rest of the wiring is 2 to 3 feet underground either as direct-bury cables or in 2”-6” PVC conduit. Most sites involve minimal grading of the land.

Every site provides access for vehicles, which requires roads, or “access aisles,” to be constructed. These roads are sometimes improved with gravel, but they do not require application of concrete or asphalt. Many sites only use gravel close to the entry to the public Right of Way, as required by NCDOT regulation, with the rest of the access aisles as simply compacted native soil. Some developers use reusable wooden logging mats to provide temporary stabilization during construction to avoid the need for the addition of gravel. A best practice when building a gravel access aisle is to strip the organic topsoil, place a geotextile fabric under the aggregate and redistribute the topsoil on site to assist in soil stabilization. This will provide stability for the aggregate, allow for more efficient removal of the gravel at the end of the project’s life cycle by providing separation between aggregate and subgrade, while preserving the valuable topsoil on site for future agricultural use. Well-drafted leases will specify allowable construction techniques and locations of roads and other infrastructure. The NC Department of Environmental Quality (DEQ) requires soil erosion and sedimentation control plans and permits and inspects implemented measures on the site until vegetative groundcover is established.

1.4 Duration of Solar Use

Currently in North Carolina most utility-scale solar projects have a 15-year Power Purchase Agreement (PPA) with the local electric utility. Some developers prefer to purchase the land, while others prefer to lease, depending on the project’s business model and financing arrangements. Typical land leases have a term of 15 to 30 years, often with several optional 5-year extensions.[10] While specific lease rates are generally undisclosed, in our understanding lease rates often range between $500 and $1,000 per acre per year. Most solar PV panel manufacturers include a 25-year power warranty on their panels, which cover the panels to produce at least 80% of their original power output at the expiration of the warranty period.

Modern solar facilities may be considered a temporary, albeit long-term, use of the land, in the sense that the systems can be readily removed from the site at the end of their productive life. At this point, the site can be returned to agricultural use, albeit with a potential for some short-term reduction in productivity due to loss of topsoil, compaction, change in pH, and change in available nutrients. Leasing farmland for solar PV use, particularly land that is not actively being farmed today, is a viable way to preserve land for potential future agricultural use. PV use is particularly valuable in this regard when compared to commercial or residential development, which require changes to the land that are very difficult to reverse. For landowners struggling to retain ownership of their land due to financial strains, solar leasing may provide a vital, stable income solution. It may also serve as a more appealing alternative to selling their land to buyers intending to use the land for other, more permanent non-agricultural uses.

While it is very difficult to predict the state of electricity, agriculture, and real estate markets 25 or more years into the future, existing circumstances can provide some insight into the likelihood of today's solar facilities continuing as solar facilities at the end of the initial PV modules' useful lifetime. The he economics of existing solar facilities are such that many of the projects built today are likely to update some of their equipment after 20 or more years and continue to operate as a solar electricity facility for many more years. The ability to facilitate interconnection to the electric grid provides great value to a landowner. A parcel of land featuring this capability in today's market will likely also appeal to solar developers in the future due to the infrastructure cost savings.

2. Weighing the Impact of PV Development on Agriculture

The purpose of this section is to explore how the competing land uses of solar development and agriculture interact and can coexist with each other. Subsection 2.1 provides analysis of data and metrics that quantify the current and potential amount of solar development on agricultural land in North Carolina. Subsection 2.2 explores the impacts that solar development could have on future agricultural production on the developed site and neighboring properties. Taken together, Section 2 of this factsheet provides several factors to consider when weighing the impact of PV development on agriculture.

2.1 Solar PV Land-Use

The NC Sustainable Energy Association (NCSEA) with the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) used GIS software to quantify the amount of solar land use. As of December 2016, solar installations occupied 0.2 percent (9,074 acres) of North Carolina's 4.75 million acres of cropland.[11] NCDA&CS has provided an updated estimate; they estimate that 14,864 acres of cropland, or 0.31 percent of the total, were occupied by solar development at the end of the first quarter of 2017.[12] NCSEA and NCDA&CS were able to locate and quantify solar use for 318 of 341 currently-installed utility-scale facilities in North Carolina. A map of the solar installations in the state prepared by NCSEA is available at: http://energyncmaps.org/gis/solar/index.html.[13] The researchers extrapolated the per-MW findings of the 318 sites found in aerial photos to generate an estimate for the remaining 23 projects not yet visible in the latest aerial photography. Across all projects, 79% of solar project area was formerly farmland, defined as land identified from aerial photography to have been used for crops, hay, or pasture before solar development. On average, the solar projects occupied 5.78 acres per MW_{AC}.

N.C. has been losing farmland to various forms of development for many years. Over the last decade, North Carolina has lost about one million acres of cropland to development and housing.

Since 1940, total cropland in N.C. has fallen from 8.42 million acres to 4.75 million acres (as of 2012). The North Carolina Department of Agriculture has identified farmland preservation as one of its top priorities since 2005.

As of the end of 2016, solar PV installations added 2,300 MWAC of solar generating capacity to North Carolina's electricity grid, making NC second in the nation for installed solar PV capacity. These installations generate enough electricity to power approximately 256,000 average N.C. homes, equaling 6.2% of all households in the state.[14] NCSEA and NCDA&CS published the summary of their land-use analysis in February of 2017 and NCSEA released a report on this research in April of this year.[15]

If the current siting and production trends were to continue until ground-mounted solar produced, on average, an amount of electricity equal to *100%* of N.C.'s current electricity use, solar facilities would cover about 8% of current N.C. cropland.[16] This is an unrealistic extreme to illustrate the limited possible magnitude of land usage for solar even at very high solar generation levels, yet even this scenario would occupy only about half of the N.C. cropland acreage lost to development in the last 10 years. Even if solar were to provide all of our electricity, ground-mounted utility-scale solar will almost certainly not be the only source of electricity. As PV prices continue to decline it is likely that North Carolina will see more and more rooftop and parking lot canopies, reducing the need for green field development. A recent Department of Energy study found that rooftop systems have the technical capability to meet 23.5% of North Carolina's electricity demand.[17]

A more likely scenario, even assuming that fossil fuel and nuclear based electricity is entirely phased out, is that other sources of renewable electricity and technologies will meet a large portion of our electricity needs. A Stanford University study of the optimal mix of renewable energy sources for each state to achieve 100% renewable energy found that North Carolina would get only 26.5% of its electricity from utility-scale solar plants.[18] At this still highly expanded level of solar development, based off of the 8.3% land use for 100% solar figure calculated earlier, the amount of NC cropland used for solar would be around 2.2%.

More realistically, in the next decade or two, solar electricity may grow to provide around 5 – 20% of North Carolina's electricity, which would allow solar to meet, or nearly meet, the full requirements of the North Carolina Renewable Energy and Energy Efficiency Portfolio Standard. At the 12.5% REPS requirement, this is about 13 GW_{AC} of PV, which will require about 75,000 acres of land at the average historic density found in the NCCETC/NCDA study. This is not an insignificant amount of land, but if split between agricultural and non-agricultural land at the same ratio as the first 2.3 GW installed in NC this represents about 1.1% of cropland in the state. NCSEA projects that by 2030, utility-scale solar will provide 5.03% of North Carolina's electricity and use 0.57% of available cropland.[19]

Solar energy's land use requirements are comparable to those of existing energy sources. According to an MIT study, supplying 100% of U.S. electricity demand in 2050 with solar would require us of about 0.4% of the country's land area; this is only half the amount of land currently used to grow corn for ethanol fuel production, and about the same amount of land as has been disturbed by surface coal mining.[20]

For landowners interested in solar development, it is important to understand the agricultural value of the land before entering into a solar lease agreement. Careful due diligence in the siting phase can help mitigate the use of the most valuable farmland. Landowners can contact their county tax office for property value information. The following online resources can assist landowners and developers in assessing the agricultural value of land before selecting the final footprint for solar development:

- www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/dma/ The USDA Natural Resources Conservation Service provides several tools in this link to identify soil types on property.
- www.ncmhtd.com/rye/ The North Carolina Realistic Yields Database provides landowners with a useful mapping and soil analysis tool that produces realistic productivity yields for expected crops given the landowner's property location and soil type.

2.2 Impact on Agricultural Productivity

This subsection provides an overview of impacts that solar development may have on agricultural land. The discussion of these impacts is divided into the following subtopics: construction grading and soil preservation, compaction, erosion, weed control, toxicity, and pollinators, followed by a brief discussion of decommissioning. The subtopic discussions illustrate that solar development, with proper planning and implementation, results in a small but manageable impact on the future agricultural productivity of the land on which it is sited. Further, these discussions also illustrate that solar development is unlikely to significantly affect the agricultural productivity of neighboring properties now or in the future.

Construction Grading and Soil Preservation

The amount of grading necessary to prepare a parcel for a utility-scale solar facility is dependent on the slope of land and the type of solar mounting used. In much of N.C., fixed-tilt mounting of PV requires little to no grading for installation of the PV system. Single-axis tracking systems that slowly rotate each row of panels to track the sun's path across the sky generally require flatter land (typically less than 8% grading) and thus more often require grading of the site, particularly for projects in the Piedmont region or farther west.[21] Typical construction practices require that topsoil be stripped and stockpiled prior to cut/fill operations. The stockpiled topsoil will be redistributed across graded areas, to assist in growing adequate ground cover as quickly as possible to provide ground stabilization. The stripping, stockpiling and redistribution of topsoil in this manner will have some impact on the amount of organics and nutrients that remain in the soil immediately after placement. However, proper ground stabilization practices include soil testing to determine the appropriate levels of lime, fertilizer and seed to be applied to establish ground cover. Proper installation practices require these additives to be tilled into the soil, which effectively reduces the compaction of the upper soil stratum, typically to a depth of 8"-12". Typical solar projects will not remove any topsoil from the project site, partly due to financial implications, but more importantly due to its value in establishing ground cover as quickly as possible[22] (removing soil also requires a mining permit).[23] Most landowners steer solar projects to their least productive soils on a given piece of property to the extent practical.[24]

Soil Quality

Modern agriculture relies on regular additions of lime and fertilizer to maintain soil pH and fertility. Solar facilities maintain vegetative ground covers that can help build soil quality over time, which may require lime and fertilizer to be applied. When the vegetation is cut, the organic matter is left in place to decompose which adds valuable organic matter to the soil. A facility operation and maintenance schedule should include a plan for maintenance of sufficient plant groundcover to protect soil from erosion. Maintaining healthy plant cover will require monitoring of soil fertility and may call for the addition of fertilizer or lime to ensure sufficient nutrients are available for plant growth and that soil pH is adequate. Vegetation mixes may help balance soil nutrient needs, but will need to be managed. Species composition will change over time.[25] NREL and others are researching and using vegetation mixes that include many native grasses with deep root systems; many include some nitrogen fixing plants as well. According to a study published in July 2016 that measured soil and air microclimate, vegetation and greenhouse gas emissions for twelve months under photovoltaic (PV) arrays, in gaps between PV arrays and in control areas at a UK solar sited on species-rich grassland, UK scientists found no change in soil properties among the three locations. After a solar project is removed, a routine soil test (available from the North Carolina Department of Agriculture) should be obtained to determine fertility requirements, including lime, for optimum crop production.

Compaction

Soil compaction can negatively impact soil productivity and will occur to some degree on every solar site. Soil compaction can also limit water infiltration into the soil environment, and lead to greater surface water runoff during rain events.[27] In addition to the roads built in and around solar project sites, the construction of the facility itself as well as regular use of lawn mowers compacts the soil, decreasing the ability of plant roots to grow. However, use of land as a solar site will avoid agriculture-related activities that can induce compaction, such as tillage. There are no data available on the degree of compaction common at solar facilities, but it is possible that some sites could experience heavy compaction in frequently used areas. In cases of heavy compaction, hard pans in the soil will form that can take decades to naturally free up; however, tractor implements such as chisels and vibrators designed to break up hard pan can often remove enough compaction to restore productivity. To prevent damage to soil due to compaction, landowners can negotiate for practices that will result in the least amount of compaction and for roads to be constructed on less productive land. Additionally, maintaining healthy groundcover, especially varieties with deep root systems, can serve to keep the soil arable for potential future agricultural use. The appropriate use of alternative vegetative maintenance strategies, such as grazing with sheep, can reduce the use of mowing equipment onsite and therefore the compaction that may result from using this equipment.[28] Furthermore, livestock grazing works to cycle nutrients in the pasture ecosystem onsite and improve the soil.

Erosion

According to its current Stormwater Design Manual, the N.C. Department of Environmental Quality allows solar panels associated with ground-mounted solar farms to be considered pervious if configured such that they promote sheet flow of stormwater from the panels and allow natural infiltration of stormwater into the ground beneath the panels.[29] For solar development, an erosion control and sedimentation permit is required, which involves on-site inspections and approval by the North Carolina Department of Environmental Quality. The permit requires establishment of permanent vegetative ground cover sufficient to restrain erosion; according to DEQ staff, the site must be "completely stabilized," although this does not require a specific percentage of ground cover.[30] In-depth information on erosion control and sedimentation laws, rules, principles, and practices is available at the NC DEQ's website, at http://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permit-guidance/erosion-sediment-control-planning-design-manual. Once permanent vegetation is established it will be necessary to maintain soil pH and fertility as mentioned above in order to ensure sufficient, healthy, and continuous ground cover for erosion control.

Weed and Vegetation Control

Maintenance of vegetation on site can be accom-

-plished using several options, including but not limited to the following: mowing, weed eaters, herbicides, and sheep. Reductions in fertilizer use on the site will slow growth of vegetation and weeds. Mowing allows the landowner to have the option of laying cut grass or vegetation on grounds of site to decompose and improve long-term soil fertility. In some cases, landowners have used grazing animals, normally sheep, to frequent the solar site grounds and control the vegetation and weeds, which also returns organic matter to the soil on site.

Like most lawns and parks, many utility-scale solar facilities in N.C. use a combination of mowing and herbicides to maintain the vegetation. When using herbicides, applicators are advised to be mindful of label instructions and local conditions. Herbicide persistence is affected by the organic matter content and moisture level of the soil. The importance of complying with legal responsibilities in using the treatments cannot be stressed enough, especially for land located near surface water, land where the surface is near the water table, or where application might carry over to other neighboring lands.

Herbicide use at solar facilities is typically similar to that in agriculture, and the types of herbicides used are similar between the two uses. As such, the impact of herbicides used at solar facilities on neighboring land and the environment is likely to be no more than that of conventional agriculture. Herbicide use differs widely among different crops and farming techniques, so the change in herbicide appliance between agricultural and solar use will vary in individual cases, but in the aggregate, there is no reason to believe that solar facilities will result in more herbicide impacts on neighboring lands than do current agricultural uses.[31] Herbicide use can be discontinued 1-2 years before decommissioning of a site, minimizing any residual impact on crop production at former solar sites.[32]

A number of sites use sheep at low densities to maintain vegetation during the growing season, although the sheep do not fully replace the need for mowing and/or herbicide use. The sheep are leased from sheep farmers, and the demand for sheep at solar facilities has been beneficial for North Carolina's sheep industry.[33] The grazing of sheep at solar facilities incorporates local farmers into the management of the sites, engaging the local community with solar development. The growth of solar farms represents a huge opportunity for the North Carolina sheep industry, with thousands of acres that are fenced well for sheep, and allow North Carolina farmers to diversify into new agricultural products for which there is increasing demand.[34]

Toxicity

There is no significant cause for concern about leaking and leaching of toxic materials from solar site infrastructure.[35] Naturally occurring rain is adequate to generally keep the panels clean enough for good electricity production. If panels do need to be washed, the washing process requires nothing more than soap and water. Additionally, the materials used to build each panel provide negligible risk of toxic exposure to the soil, environment, or people in the community. Details about toxicity for aluminum and zinc are described below, and more information on the potential for human toxicity can be found in the NCSU Health and Safety Impacts of Solar Photovoltaics white paper.

Aluminum

Aluminum is very common in soils around the world, including those common in North Carolina. In fact, the earth's crust is about 7% aluminum, and most soils are over 1% aluminum![36] The aluminum is generally unavailable to plants as long as the soil pH is above about 5.5. In acidic soils many forms of aluminum become more bio-available to plants; this can be toxic to many plant species.[37] This effect is one of the major reason many plants do not tolerate very acidic soils. The use of aluminum building materials releases negligible amounts of aluminum during their useful life because the material is so corrosion resistant.[38] The aluminum frames of PV modules are anodized which adds a very thin hard coating of aluminum oxide to the exterior of the aluminum that greatly improves aluminum's already-high resistance to corrosion. Therefore, any minute amount of aluminum that could be released by corrosion from aluminum construction materials during the life of a solar project will not materially add to the thousands or millions of pounds of aluminum naturally present in the soil of a typical N.C. solar facility. The common practice of liming soils to maintain appropriate soil pH for crop systems alleviates most, if not all, concerns about aluminum impacting crop growth in the future.

Zinc

Zinc from galvanized components, including support posts for solar panels, can move into the soil.[39] Zinc from building material stockpiles has been previously noted as a localized problem for peanut production in some North Carolina fields.[40] While it is difficult to predict in advance the degree to which this will occur, it is relatively simple to collect soil samples and monitor this situation in existing installations. Analysis of zinc is included in routine soil testing procedures used by the NC Department of Agriculture & Consumer Services Agronomic Services Division Laboratory. Awareness of zinc concentrations in the soil, and any spatial patterns noted with depth and distance from structures, should allow producers to determine if the field is adequate for desired crops as is. If zinc limitations exist, awareness of concentrations and spatial distribution patterns may indicate the potential for deep tillage, liming, or crop selection alternatives required for successful agricultural use. Of the agronomic crops grown in NC, peanuts are the most sensitive crop to zinc toxicity. Based on information from the N.C. Department of Agriculture and Consumer Services, there is risk of toxicity to peanuts when the zinc availability index (Zn-AI) is 250 or higher, particularly in low-pH situations. Risk increases with increasing soil test levels, especially if pH management through a liming program is not followed. For most other crops, zinc toxicity does not become problematic until the Zn-AI index reaches 2,000-3,000.[41]

Pollinators

Solar projects with appropriate vegetation can provide habitat for pollinators, as well as other wildlife.[42] Rather than planting common turf grasses, some solar facilities are starting to use seed mixes of native grasses and pollinator-friendly flowering plants as ground cover in solar facilities.[43,44] This provides habitat for pollinators, which can be beneficial to neighboring farms. Minnesota passed the country's first statewide standards for "pollinator friendly solar" in 2016. According to Fresh Energy, a clean energy nonprofit in St. Paul, more than 2,300 acres of these plants took root near solar panels last year, according to Fresh Energy.[45] Solar facilities can also cooperate with commercial beekeepers to facilitate honey production, although this may conflict with providing habitat for wild pollinators.[46,47] Pollinators provide benefits for agricultural production at nearby farms where insect-pollinated crops are grown.[48]

Temperature Effects

Solar PV facilities can cause changes in the air and surface temperature of the space in which they are located. The effect of solar PV facilities on surface and air temperatures is different. Solar panels shade the ground on which they are located, reducing the surface (ground) temperature from what it would be without solar panels present.[49] However, solar panels absorb solar radiation more effectively than do typical agricultural land surfaces due to their darker color, leading to an increase in air temperature directly above the solar panels as the absorbed radiation is released as heat. The decrease or increase for surface and air temperatures, respectively, is around 2-4 degrees Celsius (3.6-7.2 degrees Fahrenheit), depending on the type of land cover in the area.[50, 51]

Temperature effects on land outside the solar facility are much smaller. One study found that an air temperature increase of 1.9 degrees Celsius directly over a solar farm dissipated to 0.5 degrees Celsius at 100 meters in horizontal distance from the solar farm, and less than a 0.3 degree increase at 300 meters.[52] Another study found that a temperature difference of 3-4 degrees Celsius directly above a solar farm was dissipated to the point that it could not be measured at a distance of 100 feet from the solar farm's edge.[53] Meteorological factors can affect the range and size of any temperature effect on land nearby a solar facility, but even under very conducive circumstances the possible temperature increase for nearby land would be on the order of tenths of degrees. Studies have varied on the time at which temperature differences are most pronounced; one study noted as taking place in a desert landscape found that temperature differences were larger at night,[54] while another study found larger temperature differences during midday;[55] differences in weather and landscape between the study locations may be responsible for the different results.

Decommissioning

If land used for a solar facility is to be returned to agricultural use in the future, it will be necessary to remove the solar equipment from the land. This process is known as decommissioning. Decommissioning is basically the construction process in reverse; it involves removal of the solar panels, breakup of support pads, removal of access roads, replacement of any displaced soil, and revegetation.

Solar development often takes place on leased land, although it also occurs on land owned by solar companies. When leased land is involved, it must be determined whether the landowner or the solar developer bears responsibility for decommissioning. Responsibilities for decommissioning are lease-specific in North Carolina. It is important for landowners to consider decommissioning when setting lease terms, although landowners may choose in some cases to accept decommissioning responsibility themselves. Although state rules on solar decommissioning do not currently exist in North Carolina, local jurisdictions can choose to adopt regulations pertaining to decommissioning.

The materials recovered in the decommissioning process have significant economic value, which can help pay for the costs of decommissioning. Some engineering analyses have indicated that the salvage value of recovered materials is more than enough to pay for the removal of all the materials and to return the site to its pre-construction state.[56,57,58,59]

NCSU has produced several resources that provide more information on decommissioning. They include:

- Health and Safety Impacts of Solar Photovoltaics[60]
- Template Ordinance for Solar Energy Development in North Carolina[61]
- Working Paper: State Regulation of Solar Decommissioning[62]
- Landowner Solar Leasing: Contract Terms Explained[63]

Summary

The purpose of this paper is to explore the extent to which competition exists between solar development and agriculture and the extent to which the agricultural productivity of land is affected by solar development. Discussion on this topic was divided into two sections: (1) Understanding the Context of Solar Development and Agriculture in North Carolina and (2) Weighing the Impact of PV Development on Agriculture. In these sections, information and tools were provided to aid in understanding the impact of solar development on agricultural land. Equipped with the information and tools provided by this paper, landowners may be able to better evaluate the viability of solar development on their land.

[1] Tonya Maxwell. *Duke plans to retire Asheville coal plant, replace with natural gas*. Citizen-Times. May 19, 2015. Accessed August 2017. http://www.citizen-times.com/story/news/local/2015/05/19/duke-plans-retire-asheville-coal-plant/27571083/

[2] Duke Energy News Center. *Duke Energy's fleet modernization allows two coal plants to retire early*. February 1, 2013. Accessed August 2017. https://news.duke-energy.com/releases/duke-energy-s-fleet-modernization-allows-two-coal-plants-to-retire-early.

[3] Reuters, *Solar Power is Finding its Day in the Sun*, July 5, 2016, Accessed August 2017, http://fortune.com/2016/07/05/solar-power-is-finding-its-day-in-the-sun/.

[4] John Murawski, *NC Solar Workforce Growing Annually*, The News & Observer, February 7, 2017, Accessed August 2017, http://www.newsobserver.com/news/business/article131316314.html.

[5] John Downey, *N.C. Tops the U.S. for utility-scale solar built in Q1*. Charlotte Business Journal. May 30, 2017. Accessed August 2017. https://www.bizjournals.com/charlotte/news/2017/05/30/n-c-tops-the-u-s-for-utility-scale-solar-built-in.html.

[6] U.S. Environmental Protection Agency. *Progress Cleaning the Air and Improving People's Health*. Accessed August 4, 2017. https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health.

[7] Mike Carroll, North Carolina Cooperative Extension, personal communication, June 28, 2017.

[8] Mike Carroll, North Carolina Cooperative Extension, personal communication, June 28, 2017.

[9] Brent Niemann, Strata Solar, personal communication, June 20, 2017.

[10] Ted Feitshans, Molly Brewer. *Landowner Solar Leasing: Contract Terms Explained*. NC State Extension Publications. May 2016. Accessed March 2017. https://content.ces.ncsu.edu/landowner-solar-leasing-contract-terms-explained

[11] North Carolina Sustainable Energy Association. *Land Use Analysis of NC Solar Installations*. February 2017. Accessed March 2017. https://c.ymcdn.com/sites/energync.site-ym.com/resource/resmgr/Solar_and_Land_Use_Analysis_.pdf.

[12] Joseph Hudyncia, North Carolina Department of Agriculture and Consumer Services, personal communication, July 8, 2017.

[13] North Carolina Sustainable Energy Association. *North Carolina Installed Solar Systems*. March 2017. Accessed March 2017. http://energyncmaps.org/gis/solar/index.html

[14] North Carolina Sustainable Energy Association. *Land Use Analysis of NC Solar Installations*. February 2017. Accessed March 2017. https://c.ymcdn.com/sites/energync.site-ym.com/resource/resmgr/Solar_and_Land_Use_Analysis_.pdf

[15] North Carolina Sustainable Energy Association. *North Carolina Solar and Agriculture*. April 2017. Accessed June 2017. https://energync.org/wp-content/uploads/2017/04/NCSEA_NC_Solar_and_Agriculture_4_19.pdf

[16] 2.3 GW produce about 2.3% of NC electricity (see NCSEA's North Carolina Solar and Agriculture, April 2017) and occupies 0.19% of cropland. Multiplying 0.19% by 100%/2.3% = 8.26%. Multiplying 2.3 GW by 100%/2.3% = 100 GW and at 5.78 acres per MW this is 578,000 acres of solar projects to meet provide 100% of current NC electricity annual usage. 578,000 / 34,444,160 acres in NC is 1.7%

[17] Pieter Gagnon, Robert Margolis, Jennifer Melius, Caleb Phillips, and Ryan Elmore. *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*. National Renewable Energy Laboratory. January 2016. Accessed May 2017. http://www.nrel.gov/docs/fy16osti/65298.pdf

[18] Mark Z. Jacobson. *Repowering 100% of all Energy in the United States and the World for 100% of the People at Low Cost With Clean and Renewable Wind, Water, and Sunlight (WWS)*. Stanford University. November 2016. Accessed March 2017. http://web.stanford.edu/group/efmh/jacobson/Articles/I/16-10-31-SummaryRoadmaps.pdf

19 North Carolina Sustainable Energy Association. *North Carolina Solar and Agriculture*. April 2017.

Accessed June 2017. https://energync.org/wp-content/uploads/2017/04/NCSEA_NC_Solar_and_Agriculture_4_19.pdf
[20] MIT Energy Initiative. *The Future of Solar Energy*. May 2015. Accessed May 2017. http://energy.mit.edu/wp-content/uploads/2015/05/MITEI-The-Future-of-Solar-Energy.pdf
[21] Brent Niemann, Strata Solar, personal communication, June 20, 2017.
[22] Brent Niemann, Strata Solar, personal communication, June 20, 2017.
[23] Mike Carroll, North Carolina Cooperative Extension, personal communication, June 28, 2017.
[24] Brent Niemann, Strata Solar, personal communication, June 20, 2017.
[25] Joseph Hudyncia, North Carolina Department of Agriculture and Consumer Services, personal communication, July 8, 2017.
[26] Alona Armstrong, Nicholas Ostle, Jeanette Whitaker. *Solar Park Microclimate And Vegetation Management Effects On Grassland Carbon Cycling*. July 2016. Accessed March 2017. http://iopscience.iop.org/article/10.1088/1748-9326/11/7/074016/pdf
[27] Joseph Hudyncia, North Carolina Department of Agriculture and Consumer Services, personal communication, July 8, 2017.
[28] Brock Phillips, Sun-Raised Farms, personal communication, June 21, 2017.
[29] North Carolina Department of Environmental Quality. *Stormwater Design Manual* Ch E-6 Solar Farms. April 2017. Accessed June 2017. https://ncdenr.s3.amazonaws.com/s3fs-public/Energy%20Mineral%20and%20Land%20Resources/Stormwater/BMP%20Manual/E-6_Solar_Farms.pdf
[30] Julie Ventaloro, North Carolina Department of Environmental Quality, personal communication, June 14, 2017.
[31] North Carolina Clean Energy Technology Center. *Health and Safety Impacts of Solar Photovoltaics*. May 2017.
Accessed June 2017. https://nccleantech.ncsu.edu/wp-content/uploads/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017_white-paper.pdf
[32] Ryan Nielsen, First Solar, personal communication, June 23, 2017.
[33] Chelsea Kellner. *Got Sheep? Want a Solar Farm?* North Carolina State University College of Agricultural and Life Sciences News. September 2016. Accessed June 2017. https://cals.ncsu.edu/news/got-sheep-want-a-solar-farm/
[34] Brock Phillips, Sun-Raised Farms, personal communication, June 21, 2017.
[35] North Carolina Clean Energy Technology Center. *Health and Safety Impacts of Solar Photovoltaics*. May 2017. Accessed June 2017. https://nccleantech.ncsu.edu/wp-content/uploads/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017_white-paper.pdf
[36] NC State Cooperative Extension Service. *Extension Gardener Handbook*. February 2015. Accessed June 2017. https://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients
[37] Spectrum Analytics. *Soil Aluminum and Soil Test Interpretation*. Accessed March 2017. http://www.spectrumanalytic.com/support/library/ff/Soil_Aluminum_and_test_interpretation.htm
[38] Aluminum Design. *Aluminum Corrosion Resistance*. Accessed March 2017. http://www.aluminiumdesign.net/design-support/aluminium-corrosion-resistance/. Resource explains aluminums corrosion resistance, including the corrosion resistant benefits of anodized aluminum.
[39] American Galvanizers Association. *Hot-Dip Galvanized Steel's Contribution to Zinc Levels in the Soil Environment*. 2013. Accessed August 2017. https://www.galvanizeit.org/uploads/publications/Galvanized_Steel_Contribution_Zinc_Soil_Environment.pdf
[40] NC State Cooperative Extension Service. *Zinc Discussion*. July 2015. Accessed August 2017. https://peanut.ces.ncsu.edu/2015/07/zinc-discussion/.
[41] David H. Hardy, M. Ray Tucker, Catherine Stokes. *Understanding the Soil Test Report*. North Carolina Department of Agriculture and Consumer Services Agronomic Division. October 2013. Accessed August 2017.
http://www.ncagr.gov/agronomi/pdffiles/ustr.pdf.
[42] Press Association. *Solar farms to create natural habitats for threatened British species*. The Guardian. March 7, 2016. Accessed August 2017. https://www.theguardian.com/environment/2016/mar/07/solar-farms-to-create-natural-habitats-for-threatened-british-species.
[43] Jordan Macknick, Brenda Beatty, Graham Hill. *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. National Renewable Energy Laboratory. December 2013. Accessed August 2017.

http://www.nrel.gov/docs/fy14osti/60240.pdf

[44] Brenda Beatty, Jordan Macknick, James McCall, Genevieve Braus, David Buckner. *Native Vegetation Performance under a Solar PV Array at the National Wind Technology Center*. National Renewable Energy Laboratory. May 2017. Accessed August 2017. http://www.nrel.gov/docs/fy17osti/66218.pdf.

[45] Hannah Covington. *Ramsey energy company finds perfect pairing in putting bees, solar panels together*. Star Tribune. April 2017. Accessed June 2017. http://m.startribune.com/ramsey-energy-company-shoots-for-gooey-gold-beneath-its-solar-array/420790913/

[46] Ibid. http://m.startribune.com/ramsey-energy-company-shoots-for-gooey-gold-beneath-its-solar-array/420790913/

[47] Lina Herbertsson, Sandra A. M. Lindstrom, Maj Rundlof, Riccardo Bommarco, Henrik G. Smith. *Competition between managed honeybees and wild bumblebees depends on landscape context*. Basic and Applied Ecology. November 2016. Accessed August 2017. http://www.sciencedirect.com/science/article/pii/S1439179116300378.

[48] Lora A. Morandin, Mark L.Winston. *Pollinators provide economic incentive to preserve natural land in agroecosystems*. Agriculture, Ecosystems & Environment 116(3–4):289–292. September 2006. Accessed June 2017. http://www.sciencedirect.com/science/article/pii/S0167880906000910

[49] Mohammad M. Edalat. *Remote Sensing of the Environmental Impacts of Utility-Scale Solar Energy Plants*. UNLV University Libraries. August 2017. Accessed March 2019. https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=4078&context=thesesdissertations

[50] Vasilis Fthenakis, Yuanhao Yu. *Analysis of the Potential for a Heat Island Effect in Large Solar Farms*. 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC). Accessed March 2019. https://ieeexplore.ieee.org/abstract/document/6745171.

[51] Greg A. Barron-Gafford, Rebecca L. Minor, Nathan A. Allen, Alex D. Cronin, Adria E. Brooks, Mtchell A. Pavao-Zuckerman. T*he Photovoltaic Heat Island Effect: Larger Solar Power Plants Increase Local Temperatures*. Scientific Reports 6, Article Number 35070. October 2016. Accessed March 2019. https://www.nature.com/articles/srep35070.

[52] Vasilis Fthenakis, Yuanhao Yu. *Analysis of the Potential for a Heat Island Effect in Large Solar Farms*. 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC). Accessed March 2019. https://ieeexplore.ieee.org/abstract/document/6745171.

[53] Graham Binder, Lee Tune. *Researchers Discover Solar Heat Island Effect Caused by Large-Scale Solar Power Plants*. UMD Right Now. November 4, 2016. Accessed March 2019. https://umdrightnow.umd.edu/news/researchers-discover-solar-heat-island-effect-caused-large-scale-solar-power-plants

[54] Greg A. Barron-Gafford, Rebecca L. Minor, Nathan A. Allen, Alex D. Cronin, Adria E. Brooks, Mtchell A. Pavao-Zuckerman. T*he Photovoltaic Heat Island Effect: Larger Solar Power Plants Increase Local Temperatures*. Scientific Reports 6, Article Number 35070. October 2016. Accessed March 2019.

[55] Vasilis Fthenakis, Yuanhao Yu. *Analysis of the Potential for a Heat Island Effect in Large Solar Farms*. 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC). Accessed March 2019. https://ieeexplore.ieee.org/abstract/document/6745171.

[56] 9 RBI Solar, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in June 2016. Accessed April 2017. www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2015-05_DecommissioningPlan.pdf

[57] Birdseye Renewables, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in May 2015. Accessed April 2017. http://www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2015-04_DecommissioningPlan.pdf.

[58] Cypress Creek Renewables, Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project in September 2016. Accessed April 2017. http://www.catawbacountync.gov/Planning/Projects/Rezonings/RZ2016-06decommission.pdf.

[59] Vasilis Fthenakis, Zhuoran Zhang, Jun-Ki Choi. *Cost Optimization of Decommissioning and Recycling CdTe PV Power Plants*. IEEE Photovoltaic Specialists Conference 44. June 2017. Accessed August 2017. http://www.ieee-pvsc.org/ePVSC/core_routines/view_abstract_no.php?show_close_window=yes&abstractno=556.

[60] North Carolina Clean Energy Technology Center. *Health and Safety Impacts of Solar Photovoltaics*. May 2017. Accessed June 2017.

https://nccleantech.ncsu.edu/wp-content/uploads/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017_white-paper.pdf

[61] North Carolina Sustainable Energy Association and North Carolina Clean Energy Technology Center. *Template Solar Energy Development Ordinance for North Carolina*. October 2016. Accessed June 2017. https://nccleantech.ncsu.edu/wp-content/uploads/NC-Template-Solar-Ordinance_2016.pdf

[62] North Carolina Clean Energy Technology Center. *Working Paper: State Regulation of Solar Decommissioning*. February 2016. Accessed June 2017. https://nccleantech.ncsu.edu/wp-content/uploads/Solar-Decommissioning-Policy-Working-Paper.pdf

[63] Ted Feitshans, Molly Brewer. *Landowner Solar Leasing: Contract Terms Explained*. NC State Extension Publications. May 2016. Accessed March 2017. https://content.ces.ncsu.edu/landowner-solar-leasing-contract-terms-explained

Version 2, 05/2019
Published by the N.C. Clean Energy Technology Center at N.C. State University

Exhibit C

A Brief History of Solar Panels

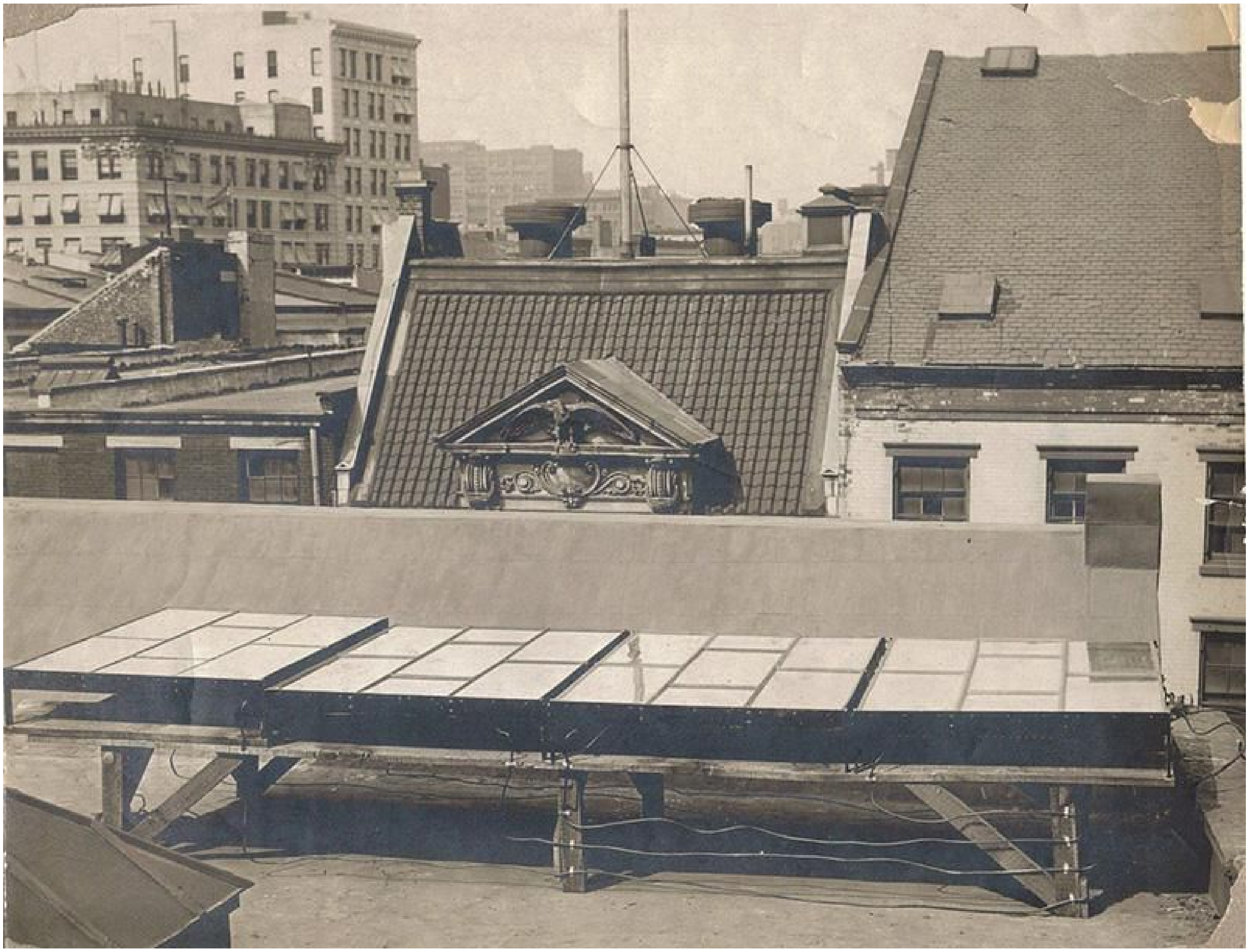
A Brief History of Solar Panels

Inventors have been advancing solar technology for more than a century and a half, and improvements in efficiency and aesthetics keep on coming

Solar has had an average annual growth rate of 50 percent in the last 10 years. (Westend61/Getty Images)

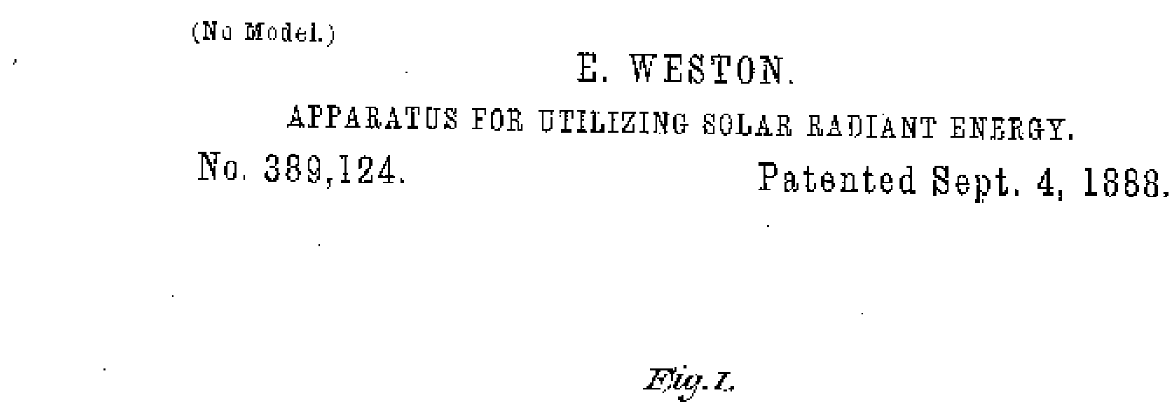
By Elizabeth Chu and D. Lawrence Tarazano, U.S. Patent and Trademark Office
smithsonianmag.com
April 22, 2019

Long before the first Earth Day was celebrated on April 22, 1970, generating awareness about the environment and support for environmental protection, scientists were making the first discoveries in solar energy. It all began with Edmond Becquerel, a young physicist working in France, who in 1839 observed and discovered the photovoltaic effect— a process that produces a voltage or electric current when exposed to light or radiant energy. A few decades later, French mathematician Augustin Mouchot was inspired by the physicist's work. He began registering patents for solar-powered engines in the 1860s. From France to the U.S., inventors were inspired by the patents of the mathematician and filed for patents on solar-powered devices as early as 1888.



Charles Fritts installed the first solar panels on New York City rooftop in 1884. (Courtesy of John Perlin)

Take a *light* step back to 1883 when New York inventor Charles Fritts created the first solar cell by coating selenium with a thin layer of gold. Fritts reported that the selenium module produced a current "that is continuous, constant, and of considerable force." This cell achieved an energy conversion rate of 1 to 2 percent. Most modern solar cells work at an efficiency of 15 to 20 percent. So, Fritts created what was a low impact solar cell, but still, it was the beginning of photovoltaic solar panel innovation in America. Named after Italian physicist, chemist and pioneer of electricity and power, Alessandro Volta, photovoltaic is the more technical term for turning light energy into electricity, and used interchangeably with the term photoelectric.

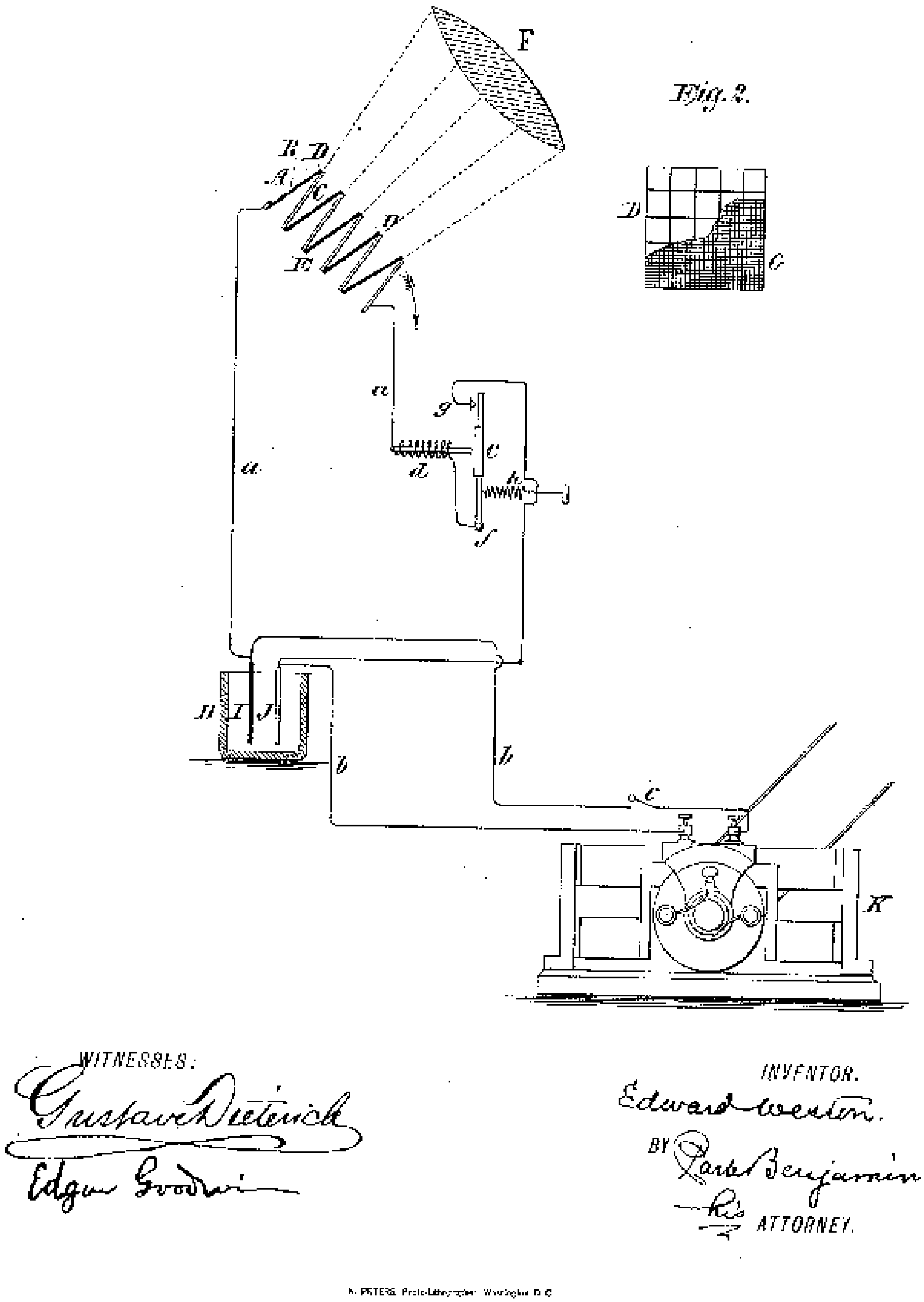

(No Model.)

E. WESTON.

APPARATUS FOR UTILIZING SOLAR RADIANT ENERGY.

No. 389,124. Patented Sept. 4, 1888.

Fig. 1.



Edward Weston's "Apparatus for Utilizing Solar Radiant Energy," patented September 4, 1888. (U.S. Patent 389,124)

Only a few years later in 1888, inventor Edward Weston received two patents for solar cells – U.S. Patent 389,124 and U.S. Patent 389,425. For both patents, Weston proposed, “to transform radiant energy derived from the sun into electrical energy, or through electrical energy into mechanical energy.” Light energy is focused via a lens (f) onto the solar cell (a), “a thermopile (an electronic device that converts thermal energy into electrical energy) composed of bars of dissimilar metals.” The light heats up the solar cell and causes electrons to be released and current to flow. In this instance, light creates heat, which creates electricity; this is the exact reverse of the way an incandescent light bulb works, converting electricity to heat that then generates light.

That same year, a Russian scientist by the name of Aleksandr Stoletov created the first solar cell based on the photoelectric effect, which is when light falls on a material and electrons are released. This effect was first observed by a German physicist, Heinrich Hertz. In his research, Hertz discovered that more power was created by ultraviolet light than visible light. Today, solar cells use the photoelectric effect to convert sunlight into power. In 1894, American inventor Melvin Severy received patents 527,377 for an "Apparatus for mounting and operating thermopiles" and 527,379 for an "Apparatus for generating electricity by solar heat." Both patents were essentially early solar cells based on the discovery of the photoelectric effect. The first generated “electricity by the action of solar heat upon a thermo-pile” and could produce a constant electric current during the daily and annual movements of the sun, which alleviated anyone from having to move the thermopile according to the sun’s movements. Severy’s second patent from 1889 was also meant for using the sun’s thermal energy to produce electricity for heat, light and power. The “thermos piles,” or solar cells as we call them today, were mounted on a standard to allow them to be controlled in the vertical direction as well as on a turntable, which enabled them to move in a horizontal plane. “By the combination of these two movements, the face of the pile can be maintained opposite the sun all times of the day and all seasons of the year,” reads the patent.

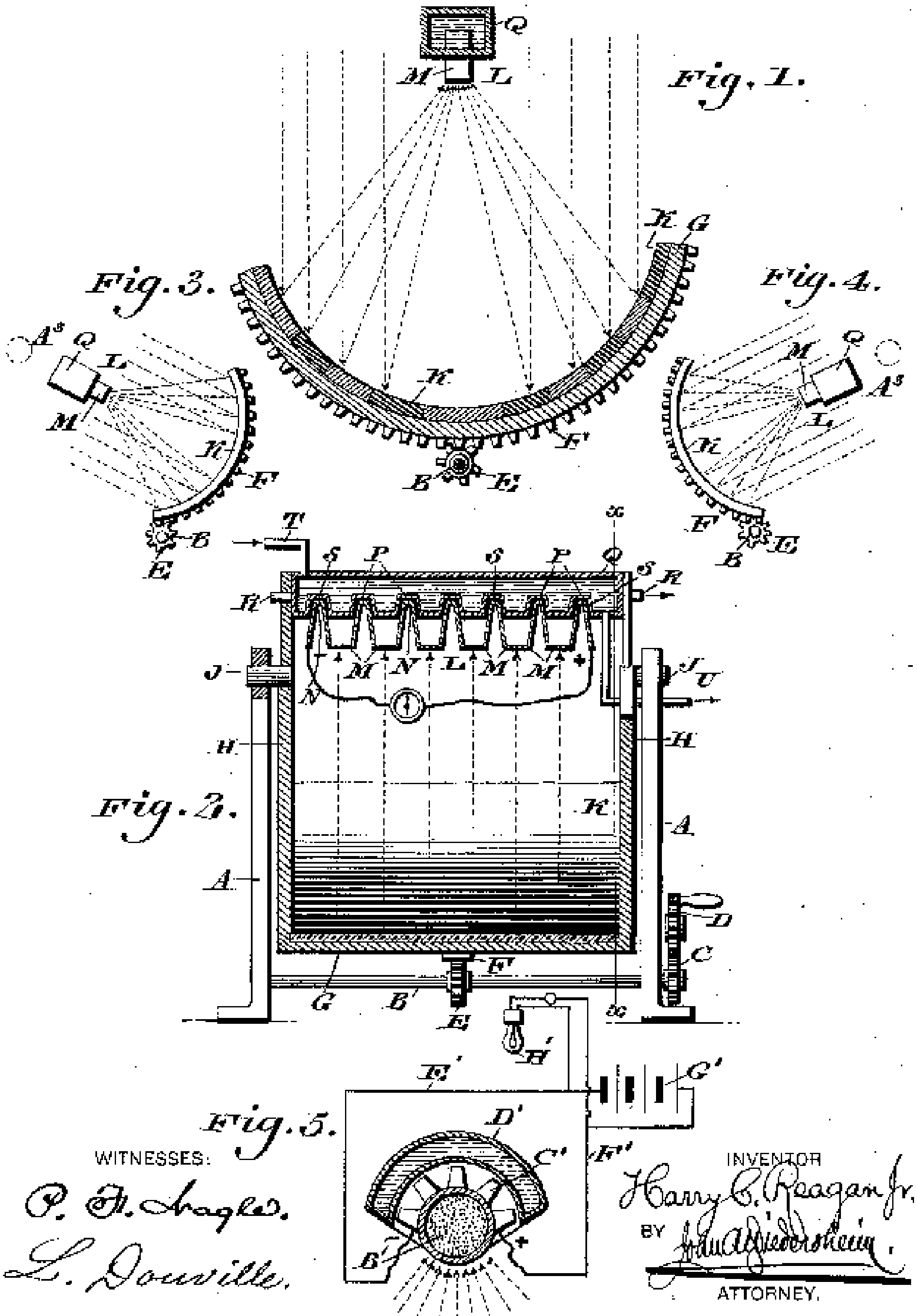
Almost a decade later, American inventor Harry Reagan received patents for thermal batteries, which are structures used to store and release thermal energy. The thermal battery was invented to collect and store heat by having a large mass that can heat up and release energy. It does not store electricity but “heat,” however, systems today use this technology to generate electricity by conventional turbines. In 1897, Reagan was granted U.S. patent 588,177 for an “application of solar heat to thermo batteries.” In the claims of the patent, Reagan said his invention included “a novel construction of apparatus in which the sun’s rays are utilized for heating thermo-batteries, the object being to concentrate the sun’s rays to a focus and have one set of junctions of a thermo-battery at the focus of the rays, while suitable cooling devices are applied to the other junctions of said thermo-battery.” His invention was a means to collecting, storing and distributing solar heat as needed.

(No Model.) 2 Sheets—Sheet 1.

H. C. REAGAN, Jr.

APPLICATION OF SOLAR HEAT TO THERMO BATTERIES.

No. 588,177. Patented Aug. 17, 1897.

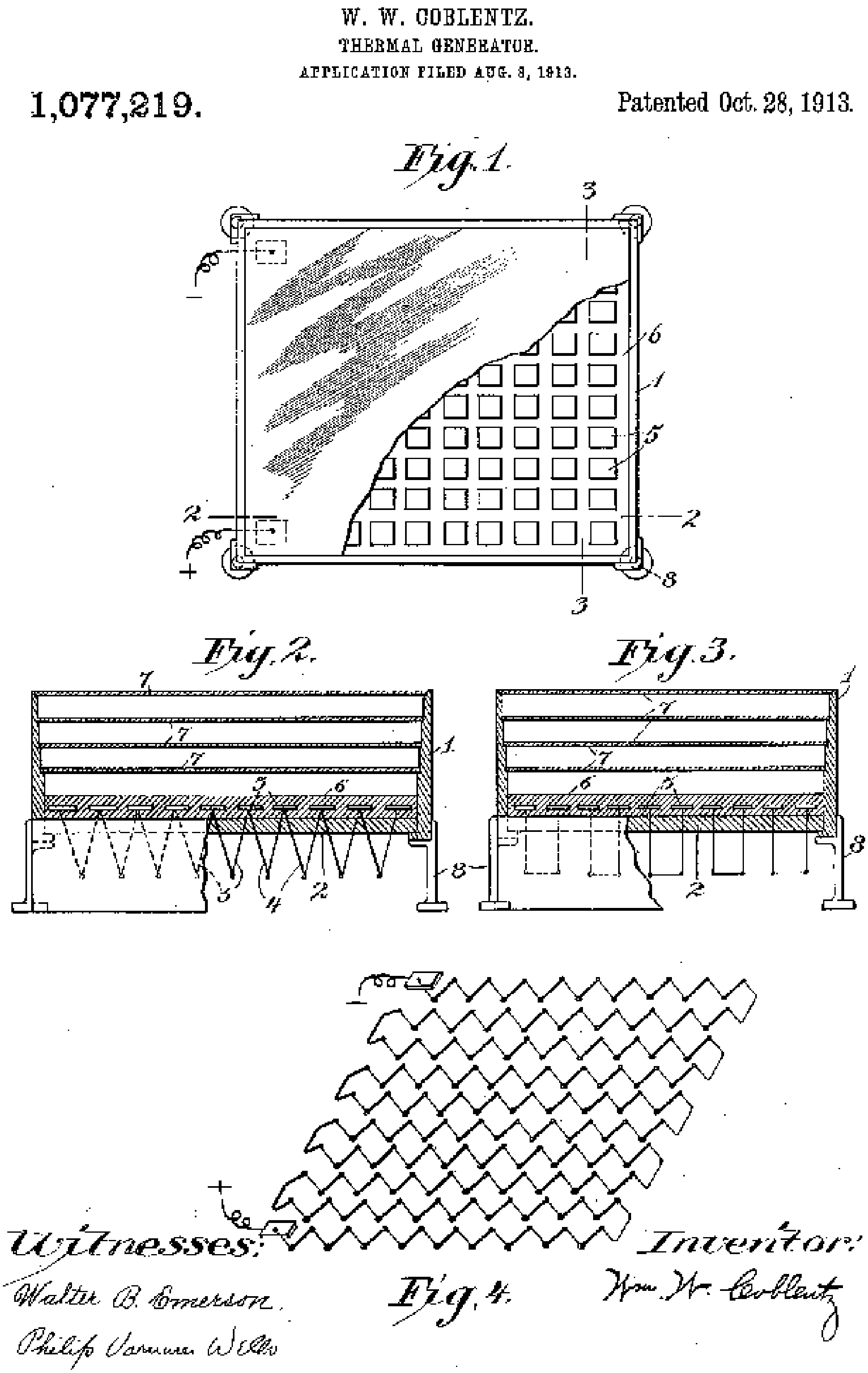


WITNESSES:
P. H. Nagle.
L. Douville.

INVENTOR
Harry C. Reagan Jr.
BY
ATTORNEY.

H.C. Reagan's "Application of Solar Heat to Thermo Batteries," patented August 17, 1897 (U.S. Patent 588,177)

In 1913, William Coblentz, of Washington, D.C., received patent 1,077,219 for a “thermal generator,” which was a device that used light rays “to generate an electric current of such a capacity to do useful work.” He also meant for the invention to have cheap and strong construction. Although this patent was not for a solar panel, these thermal generators were invented to either convert heat directly into electricity or to transform that energy into power for heating and cooling.


W. W. COBLENTZ.
THERMAL GENERATOR.
APPLICATION FILED AUG. 8, 1913.
1,077,219.
Patented Oct. 28, 1913.
Fig. 1.
Fig. 2.
Fig. 3.
Witnesses:
Walter B. Emerson.
Inventor:
Wm. W. Coblentz
Fig. 4.

W.W. Coblentz's "Thermal Generator," patented October 28, 1913 (U.S. Patent 1,077,219)

By the 1950s, Bell Laboratories realized that semiconducting materials such as silicon were more efficient than selenium. They managed to create a solar cell that was 6 percent efficient. Inventors Daryl Chapin, Calvin Fuller, and Gerald Pearson (inducted to the National Inventors Hall of Fame in 2008) were the brains behind the silicon solar cell at Bell Labs. While it was considered the first practical device for converting solar energy to electricity, it was still cost prohibitive for most people. Silicon solar cells are expensive to produce, and when you combine multiple cells to create a solar panel, it's even more expensive for the public to purchase. University of Delaware is credited with creating one of the first solar buildings, "Solar One," in 1973. The construction ran on a combination of solar thermal and solar photovoltaic power. The building didn't use solar panels; instead, solar was integrated into the rooftop.

Feb. 5, 1957 D. M. CHAPIN ET AL 2,780,765

SOLAR ENERGY CONVERTING APPARATUS

Filed March 5, 1954

FIG. 1

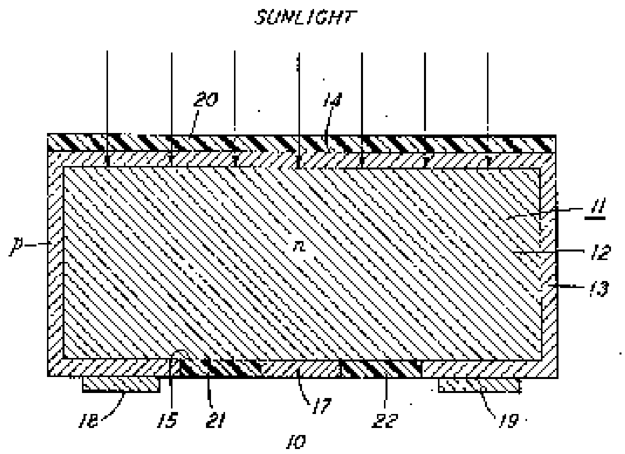
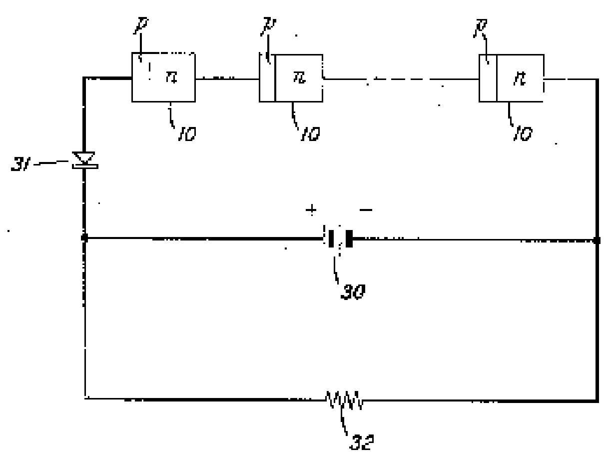


FIG. 2



INVENTORS: D. M. CHAPIN
C. S. FULLER
G. L. PEARSON

BY Arthur J. Torsiglieri
ATTORNEY

D. M. Chapin et al's "Solar Energy Converting Apparatus," patented February 5, 1957 (U.S. Patent 2,780,765)

It was around this time in the 1970s that an energy crisis emerged in the United States. Congress passed the Solar Energy Research, Development and Demonstration Act of 1974, and the federal government was committed more than ever "to make solar viable and affordable and market it to the public." After the debut of "Solar One," people saw solar energy as an option for their homes. Growth slowed in the 1980s due to the drop in traditional energy prices. But in the next decades, the federal government was more involved with solar energy research and development, creating grants and tax incentives for those who used solar systems. According to Solar Energy Industries Association, solar has had an average annual growth rate of 50 percent in the last 10 years in the United States, largely due to the Solar Investment Tax Credit enacted in 2006. Installing solar is also more affordable now due to installation costs dropping over 70 percent in the last decade.

That said, at least until recently, the means to find a viable and affordable energy solution is more important than making solar cells aesthetically pleasing or beautiful. Traditional solar panels on American rooftops aren't exactly subtle or pleasing to the eye. They've been an eyesore for neighbors at times, and surely a pain for homeowners associations to deal with, but the benefits to the environment are substantial. So, where's the balance? Today, companies are striving towards better looking and advanced solar technology, such as building-applied photovoltaic (BAPV). This type of discreet solar cell is integrated into existing roof tiles or ceramic and glass facades of buildings.

Solus Engineering, Enpulz, Guardian Industries Corporation, SolarCity Corporation, United Solar Systems, and Tesla (after their merger with SolarCity) have all been issued patents for solar cells that are much more discreet than the traditional solar panel. All of the patents incorporate photovoltaic systems, which transform light into electricity using semiconducting materials such as silicon. Solar panels and solar technology has come a long way, so these patented inventions are proof that the technology is still improving its efficiency *and* aesthetics.

Exhibit D

Study Acoustic EMF Levels Solar Photovoltaic Projects

STUDY OF ACOUSTIC AND EMF LEVELS FROM SOLAR PHOTOVOLTAIC PROJECTS

Prepared for:
Massachusetts Clean Energy Center
9th Floor
55 Summer Street
Boston, MA 02110

Prepared by:
Tech Environmental, Inc.
303 Wyman Street, Suite 295
Waltham, MA 02451

STUDY OF ACOUSTIC AND EMF LEVELS FROM SOLAR PHOTOVOLTAIC PROJECTS

Prepared for:

Massachusetts Clean Energy Center
9th Floor
55 Summer Street
Boston, MA 02110

Prepared by:

Peter H. Guldberg, INCE, CCM
Tech Environmental, Inc.
303 Wyman Street, Suite 295
Waltham, MA 02451

December 17, 2012

ACKNOWLEDGEMENTS

The study team would like to thank the owners and managers of the four project sites for participating in this study and their cooperation in gaining access to the sites, operational data, and system specifications.

We would also like to thank Bram Claeys of the Massachusetts Department of Energy Resources as well as Elizabeth Kennedy and Peter McPhee of the Massachusetts Clean Energy Center for their thorough and insightful review of this study.

EXECUTIVE SUMMARY

Sound pressure level and electromagnetic field (EMF) measurements were made at three utility-scale sites with solar photovoltaic (PV) arrays with a capacity range of 1,000 to 3,500 kW (DC at STC) under a full-load condition (sunny skies and the sun at an approximate 40^{o} azimuth). Measurements were taken at set distances from the inverter pads and along the fenced boundary that encloses the PV array. Measurements were also made at set distances back from the fenced boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of equipment sound levels.

EMF measurements were also made at one residential PV installation with a capacity of 8.6 kW under a partial-load condition. PV array operation is related to the intensity of solar insolation. Less sunshine results in lower sound and EMF levels from the equipment, and no sound or EMF is produced at night when no power is produced. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

Sound levels along the fenced boundary of the PV arrays were generally at background levels, though a faint inverter hum could be heard at some locations. Any sound from the PV array and equipment was inaudible at set back distances of 50 to 150 feet from the boundary. Average L_{eq} sound levels at a distance of 10 feet from the inverter face varied over the range of 48 dBA to 61 dBA for Site 2 and Site 3 Inverters[1], and were higher in the range of 59 to 72 dBA for Site 1 Inverters. Along the axis perpendicular to the plane of the inverter face and at distances of 10 to 30 feet, sound levels were 4 to 13 dBA higher compared to levels at the same distance along the axis parallel to the inverter face. At 150 feet from the inverter pad, sound levels approached background levels. Sound level measurements generally followed the hemispherical wave spreading law (-6 dB per doubling of distance).

The time domain analysis reveals that 0.1-second L_{eq} sound levels at a distance of 10 feet from an inverter pad generally varied over a range of 2 to 6 dBA, and no recurring pattern in the rise and fall of the inverter sound levels with time was detected. The passage of clouds across the face of the sun caused cooling fans in the inverters to briefly turn off and sound levels to drop 4 dBA.

[1] The same make of inverters were used at Sites 2 and 3.

The 1/3-octave band frequency spectrum of inverter sound at the close distance of 10 feet shows energy peaks in several mid-frequency and high-frequency bands, depending on the inverter model. Tonal sound was found to occur in harmonic pairs: 63/125 Hz; 315/630 Hz; 3,150/6,300 Hz; and 5,000/10,000 Hz. The high frequency peaks produce the characteristic “ringing noise” or high-frequency buzz heard when one stands close to an operating inverter. The tonal sound was not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum. All low-frequency sound from the inverters below 40 Hz is inaudible, at all distances.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has a recommended electric field level exposure limit of 4,200 Volts/meter (V/m) for the general public. At the utility scale sites, electric field levels along the fenced PV array boundary, and at the locations set back 50 to 150 feet from the boundary, were not elevated above background levels (< 5 V/m). Electric fields near the inverters were also not elevated above background levels (< 5 V/m). At the residential site, indoor electric fields in the rooms closest to the roof-mounted panels and at locations near the inverters were not elevated above background levels (< 5 V/m).

The International Commission on Non-Ionizing Radiation Protection has a recommended magnetic field level exposure limit of 833 milli-Gauss (mG) for the general public. At the utility scale sites, magnetic field levels along the fenced PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations 50 to 150 feet from the fenced array boundary were not elevated above background levels (<0.2 mG). There are significant magnetic fields at locations a few feet from these utility-scale inverters, in the range of 150 to 500 mG. At a distance of 150 feet from the inverters, these fields drop back to very low levels of 0.5 mG or less, and in many cases to background levels (<0.2 mG). The variation of magnetic field with distance generally shows the field strength is proportional to the inverse cube of the distance from equipment.

At the residential site, indoor magnetic field levels in the rooms closest to the roof-mounted panels were in the low range of 0.2 to 1.4 mG. There are low-level magnetic fields at locations a few feet from the inverters, in the range of 6 to 10 mG. At a distance of no more than 9 feet from the inverters, these fields dropped back to the background level at this residential site of 0.2 mG. Due to the relatively high background level in the residential site basement where the inverters were housed, the relationship of magnetic field strength to distance from the inverters could not be discerned.

TABLE OF CONTENTS

Section **Contents** **Page**

1.0 INTRODUCTION

The goal of this study is to conduct measurements at several ground-mounted PV arrays in Massachusetts to determine the sound pressure levels and electromagnetic field (EMF) levels generated by PV arrays and the equipment pads holding inverters and small transformers. This information will be used to inform local decision-makers and the public about the acoustic and EMF levels in the vicinity of PV projects.

Measurements were made at three utility-scale sites having PV arrays with a capacity range of 1,000 to 3,500 kW (DC at STC), with weather conditions consisting of sunny skies and the sun at approximately 40^{o} azimuth. Measurements were also made at one residential[2] PV installation with a capacity of 8.6 kW under a partial-load condition. Sound level and EMF data were collected at set distances from the inverter pads and along the fenced boundary of the PV array. Measurements were also made at set distances back from the fenced boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of equipment sound levels. Figure 1 shows a schematic map of a typical utility scale PV array containing four inverter pads and a fenced boundary. The orange stars show typical measurement locations around the fenced boundary of the array and at fixed set back distances of 50 feet, 100 feet, and 150 feet from the boundary. The green stars represent typical measurement locations at three set back distances from inverters on two of the equipment pads. At each equipment pad that was sampled, sound level measurements were made in two directions: along an axis parallel to the inverter face and along an axis perpendicular to the inverter face. Figure 2 illustrates a sound meter setup along the axis perpendicular to (90^{o} from) an inverter face.

Section 2.0 of this report describes the measurement methods and locations, while Section 3.0 presents the measurement results in detail for the four sites. Study conclusions are given in Section 4.0. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

[2] Only EMF measurements were made at the residential site.

Figure 1. Schematic Map of Sound and EMF Measurement Locations at a Solar Photovoltaic (PV) Array

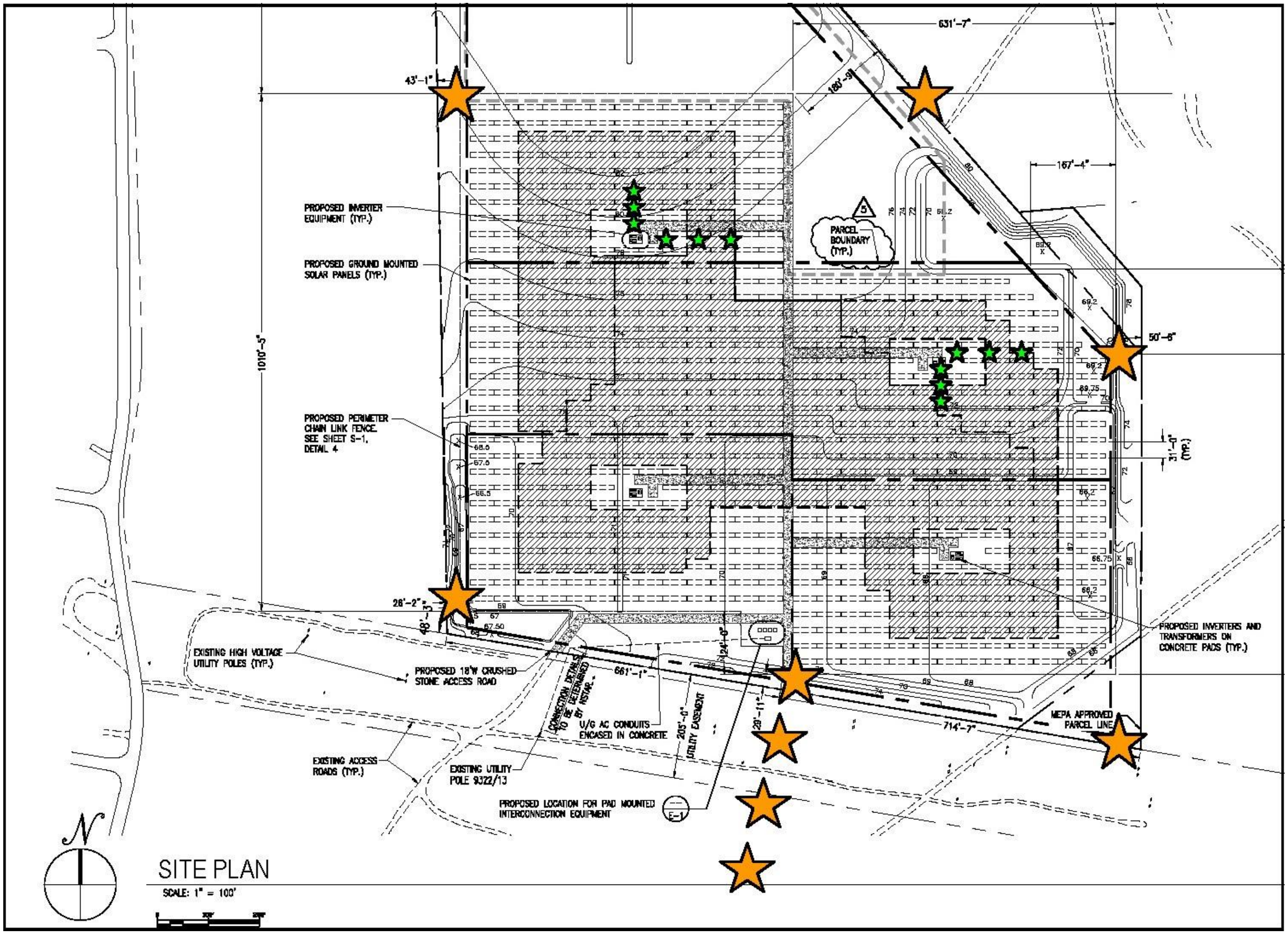


Figure 2. Sound Level Meter on the Axis Perpendicular to the Face of an Inverter at a Solar Photovoltaic (PV) Array

2.0 MEASUREMENT METHODS AND LOCATIONS

Sound pressure and EMF levels were measured along the fenced boundary of each PV array, at three set back distances from the boundary, and at fixed distances from equipment pads housing inverters and transformers (see Figures 1 and 2). Sound levels were measured with a tripod-mounted ANSI Type 1 sound meter, a Bruel & Kjaer Model 2250 meter, equipped with a large 7-inch ACO-Pacific WS7-80T 175 mm (7-inch) wind screen that is oversize and specially designed to screen out wind flow noise. An experimental study of wind-induced noise and windscreen attenuation effects by Hessler[3] found that the WS7-80T windscreen keeps wind-induced noise at the infrasound frequency band of 16 Hz to no more than 42 dB for moderate across-the–microphone wind speeds. That minimal level of wind-induced noise is 8 to 20 dB below the 16-Hz levels measured in this study.

The B&K Model 2250 measures 1/3-octave bands down to 6.3 Hz, well into the infrasonic range, and up to 20,000 Hz, the upper threshold of human hearing. The sound meter first recorded short-term (1-minute L_{eq} and L_{90}) broadband sound levels (in A-weighted decibels, dBA) at the established survey points. Then the sound meter was placed at the nearest measurement distance to each equipment pad to record a 10-minute time series of broadband and 1/3-octave band L_{eq} sound levels (in decibels, dB) at 0.1-second intervals. The L_{90} sound level removes intermittent noise and thus is lower than the L_{eq} sound level in the tables of results provided in Section 3.

EMF levels of both the magnetic field (in milliGauss, mG) and the electric field (in Volts/meter, V/m) were measured using a pair of Trifield Model 100XE EMF Meters. These instruments perform three-axis sampling simultaneously, enabling rapid survey of an area. The Trifield meters have a range for magnetic fields of 0.2 to 10,000 mG, and for electric fields from 5 to 1,000 V/m. EMF measurements were taken at the same survey points as the sound level measurements.

Measurements were made along the fenced boundary around each PV array at four to six evenly-spaced locations (depending on the size of the array), and at three additional locations set back 50 feet, 100 feet, and 150 feet from the boundary. At each equipment pad that was sampled, sound level

[3] Hessler, G., Hessler, D., Brandstatt, P., and Bay, K., "Experimental study to determine wind-induced noise and windscreen attenuation effects on microphone response for environmental wind turbine and other applications", Noise Control Eng. J., 56(4), 2008.

measurements were made in two directions: parallel to the inverter face, and perpendicular to the equipment face. The closest sound monitoring location was selected at a distance "1X" where the inverter or transformer sound was clearly audible above background levels. The closest EMF monitoring location was selected at a distance "1X" where magnetic field levels were approximately 500 mG, a level that is below the ICNIRP-recommended[4] human exposure limit of 833 mG (see Appendix B). Additional sampling points were then placed at distances[5] of 2X, 3X, and at 150 feet from the equipment pad, in the two orthogonal directions. There were a total of eight monitoring locations for each equipment pad, and seven to nine locations for the PV array boundary.

Measurements were made on October 11, 17, 22 and 26, 2012 around 12:30 p.m. EDT, the time of peak solar azimuth, and only on days for which clear skies were forecast to maximize solar insolation to the PV array. The peak solar azimuth in southern Massachusetts was approximately 40^{o} azimuth on these dates. Consistent with standard industry practice, background levels of sound and EMF were measured at representative sites outside the fenced boundary of the PV array and far enough away to not be influenced by it or any other significant nearby source. The background levels presented for each site were made at distances of 50 feet, 100 feet, and 150 feet from the fenced boundary around the PV array (see Figure 1).

4 International Commission on Non-Ionizing Radiation Protection.

5 Location 2X is twice the distance from the equipment as location 1X; Location 3X is three times that distance.

3.0 MEASUREMENT RESULTS

Sound and EMF measurements were made at the following four PV arrays, presented in the following sections:

Site 1 – Achusnet ADM, Wareham, MA
Site 2 – Southborough Solar, Southborough, MA
Site 3 – Norfolk Solar, Norfolk, MA
Site 4 – Residential PV array owned by Massachusetts Audubon Society, Sharon, MA

3.1 Site 1 – Achusnet ADM

Facility Location:	27 Charlotte Furnace Road, Wareham, MA
Facility Owner:	Borrego Solar Systems, Inc.
System Capacity:	3,500 kW
Power Output During Monitoring:	3,500 kW
No. & Size Inverters:	(7) 500-kW inverters
Date Measured:	Thursday October 11, 2012
Cloud Cover:	0%
Winds:	West 10-12 mph
Ground:	Open area between cranberry bogs, no buildings or vegetation.
Background Sound:	Mean value L_{eq} of 46.4 dBA (range of 45.6 to 47.0 dBA). Mean value of L_{90} 43.9 dBA (range of 41.6 to 45.4 dBA). Sources included highway traffic on I-495 (to the south), earthmoving equipment to the east, birds and other natural sounds.
Background EMF:	None (< 0.2 mG and < 5 V/m) except along southern boundary from hi-voltage power lines overhead, and near the eastern boundary from low-voltage power lines overhead.

The solar photovoltaic array is in a flat area between cranberry bogs east of Charlotte Furnace Road in Wareham and the boundary of the array is fenced. The surrounding area has no buildings or vegetation. There are four equipment pads within the PV array, each housing one or two inverters. Measurements were made at two equipment pads: 1) the Northwest Pad, which contains two inverters and a small transformer, and 2) the Northeast Pad, which has one inverter and a small transformer. The sound and EMF measurements made at Site 1 are summarized in Tables 1 through 3. Figures 3 and 4 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location

(1X) for the Northwest and Northeast Equipment Pads, while Figure 5 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

Sound Levels

Background sound levels varied over time and space across the site. Highway traffic noise was the primary background sound source and higher levels were measured for locations on the south side of the site closer to the highway. Variable background sound was also produced by trucking activity to the east of the PV array, where sand excavated during the PV array's construction and stored in large piles was being loaded with heavy equipment into dump trucks and hauled away. Background sound levels varied over a range of 6 dBA. Background mean value L_{eq} and L_{90} levels were 46.4 dBA and 43.9 dBA, respectively. The PV array was inaudible outside of the fenced boundary, and was also inaudible everywhere along the boundary except at the North East boundary location where a faint inverter hum could be heard. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the North West Pad (which holds two 500-kW inverters) were 68.6 to 72.7 dBA and at the same distance from the North East Pad (which holds only one 500-kW inverter) were lower at 59.8 to 66.0 dBA. Along the axis perpendicular to the inverter face measured sound levels were 4 to 6 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels generally declined with distance following the hemispherical wave spreading law (approximately -6 dB per doubling of distance) and at a distance of 150 feet all inverter sounds approached background sound levels. Due to the layout of the solar panels, the measurements made perpendicular to the inverter face and at a distance of 150 feet were blocked from a clear line of sight to the inverter pad by many rows of solar panels, which acted as sound barriers.

The time domain analysis presented in Figures 3 and 4 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 3 to 4 dBA at the North West Pad and 2 to 3 dBA at the North East Pad. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. The inverters registered full 500-kW capacity during both 10-minute monitoring periods.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 5) shows energy peaks in four 1/3-octave bands, which are most pronounced for the North West Pad: 315 Hz, 630 Hz, 3,150 Hz, and 6,300 Hz. The two higher frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak in each pair is a first-harmonic tone (6,300 Hz being twice the frequency of 3,150 Hz). The tonal sound exhibited by Figure 5 is not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 5. The dashed line in Figure 5 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum is smooth except for a broad peak around 800 Hz caused by distant highway traffic noise and a peak at 8,000 Hz that represents song birds.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the boundary, are not elevated above background levels (< 5 V/m). The one measurement at 5.0 V/m in Table 1 was caused by the field around a nearby low-voltage power line overhead. Electric fields near the inverters are also not elevated above background levels (< 5 V/m). The one measurement at 10.0 V/m in Table 3 was caused by the meter being close to the front face of a solar panel at the 150-foot set back distance.

Magnetic Fields

Magnetic field levels along the PV array boundary and 50 feet from the boundary were in the very low range of 0.2 to 0.3 mG, except at the southern end of the boundary that is close to overhead high-voltage power lines, owned by the local utility and not connected to the project, where levels of 0.7 to 3 mG were measured, caused by those hi-voltage power lines. Magnetic field levels at the location 100 feet from the boundary were elevated by a low-voltage power line overhead. At 150 feet from the boundary, the magnetic field is not elevated above background levels (<0.2 mG).

Table 3 reveals that there are significant magnetic fields at locations a few feet from inverters, around 500 mG. These levels drop back to 0.2 to 0.5 mG at distances of 150 feet from the inverters. The variation of magnetic field with distance shown in Table 3 generally shows the field strength is proportional to the inverse cube of the distance from equipment. Following that law, the magnetic field at 5 feet of 500 mG should decline to 0.02 mG (< 0.2 mG) at 150 feet. The measured levels of 0.1 to 0.5 mG at 150 feet listed in Table 3 are likely caused by small-scale magnetic fields setup around the PV cells and connecting cables near the sampling locations.

TABLE 1

SOUND AND EMF LEVELS MEASURED AT SITE 1
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	39.1	42.5	< 0.2	< 5
South West Boundary	43.6	44.7	1.8	< 5
South Center Boundary	44.8	48.1	3.0	< 5
South East Boundary	44.0	45.6	0.7	< 5
North East Boundary	42.2	43.9	< 0.2	< 5
North Center Boundary	43.4	44.3	0.3	< 5
Background Mean Values	43.9	46.4	< 0.2	< 5
Set back 50 feet from Boundary	41.6	47.0	0.2	< 5
Set back 100 feet from Boundary	45.4	46.7	0.4	5.0
Set back 150 feet from Boundary	44.7	45.6	< 0.2	< 5

TABLE 2

SOUND LEVELS MEASURED AT SITE 1
EQUIPMENT PADS

Equipment Pad / Direction / Distance	L_{90} Level (dBA)	L_{eq} Level (dBA)
North West Pad / Parallel to Inverter Face / 10 feet	67.6	68.6
North West Pad / Parallel to Inverter Face / 20 feet	61.8	63.1
North West Pad / Parallel to Inverter Face / 30 feet	58.8	60.6
North West Pad / Parallel to Inverter Face / 150 feet	45.2	46.0
North West Pad / Perpendicular to Inverter Face / 10 feet	71.8	72.7
North West Pad / Perpendicular to Inverter Face / 20 feet	63.5	64.8
North West Pad / Perpendicular to Inverter Face / 30 feet	59.5	62.3
North West Pad / Perpendicular to Inverter Face / 150 feet	41.8	43.0
North East Pad / Parallel to Inverter Face / 10 feet	59.1	59.8
North East Pad / Parallel to Inverter Face / 20 feet	55.4	56.2
North East Pad / Parallel to Inverter Face / 30 feet	54.8	55.7
North East Pad / Parallel to Inverter Face / 150 feet	43.4	44.0
North East Pad / Perpendicular to Inverter Face / 10 feet	65.5	66.0
North East Pad / Perpendicular to Inverter Face / 20 feet	59.8	60.2
North East Pad / Perpendicular to Inverter Face / 30 feet	56.3	56.9
North East Pad / Perpendicular to Inverter Face / 150 feet	41.0	43.6

TABLE 3

**EMF LEVELS MEASURED AT SITE 1
EQUIPMENT PADS**

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
North West Pad / Parallel to Inverter Face / 5 feet 3 inches	500	< 5
North West Pad / Parallel to Inverter Face / 10 feet 6 inches	10.5	< 5
North West Pad / Parallel to Inverter Face / 15 feet 9 inches	2.75	< 5
North West Pad / Parallel to Inverter Face / 150 feet	0.2	< 5
North West Pad / Perpendicular to Inverter Face / 4 feet	500	< 5
North West Pad / Perpendicular to Inverter Face / 8 feet	200	< 5
North West Pad / Perpendicular to Inverter Face / 12 feet	6.5	< 5
North West Pad / Perpendicular to Inverter Face / 150 feet	0.5	< 5
North East Pad / Parallel to Inverter Face / 3 feet 10 inches	500	< 5
North East Pad / Parallel to Inverter Face / 7 feet 8 inches	30	< 5
North East Pad / Parallel to Inverter Face / 11 feet 10 inches	4.5	< 5
North East Pad / Parallel to Inverter Face / 150 feet	0.2	10.0
North East Pad / Perpendicular to Inverter Face / 7 feet 6 inches	500	< 5
North East Pad / Perpendicular to Inverter Face / 15 feet	10	< 5
North East Pad / Perpendicular to Inverter Face / 22 feet 6 inches	2.1	< 5
North East Pad / Perpendicular to Inverter Face / 150 feet	0.1	< 5

Figure 3. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1

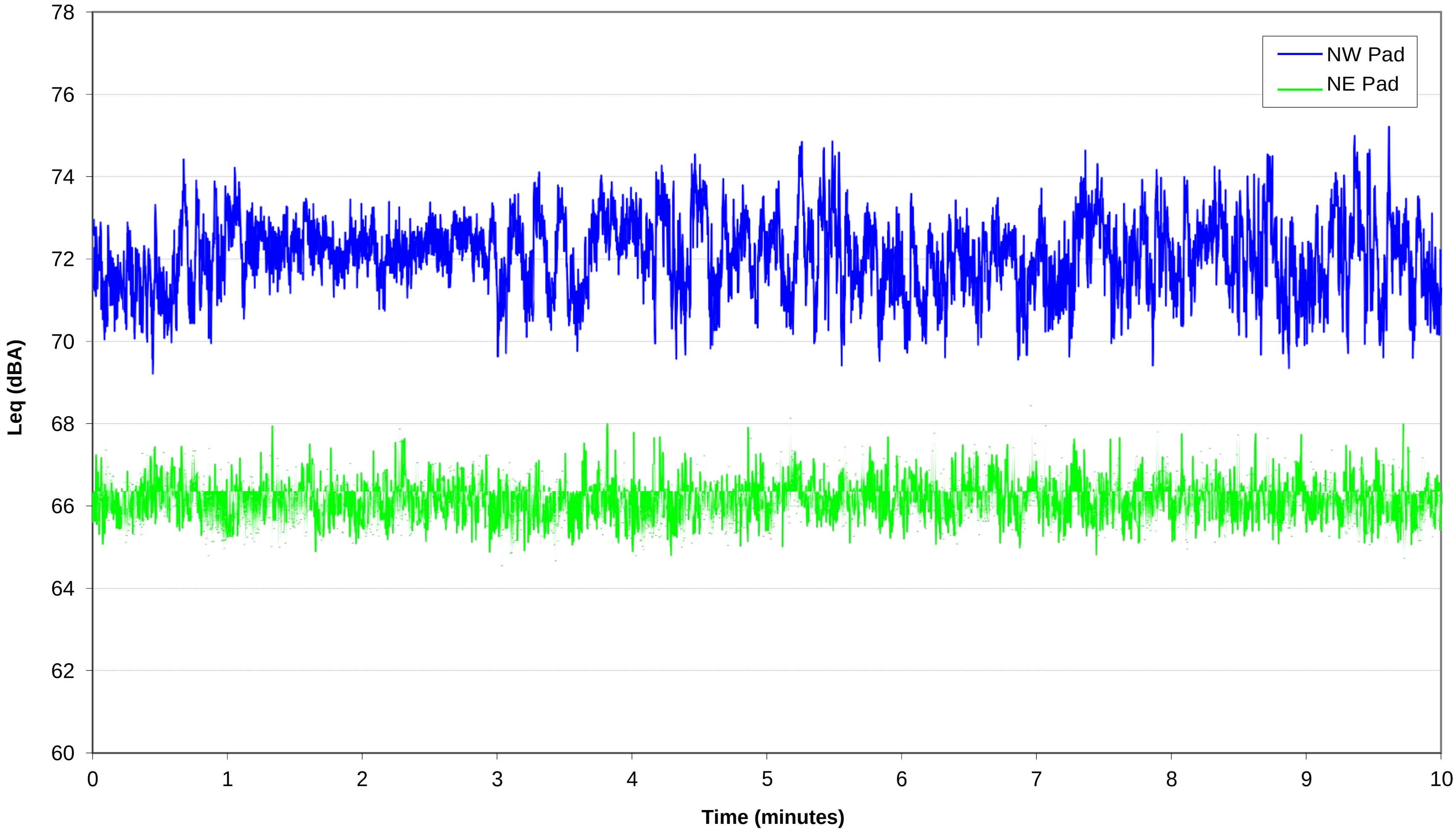


Figure 4. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1 - First 10 Seconds of Measurements

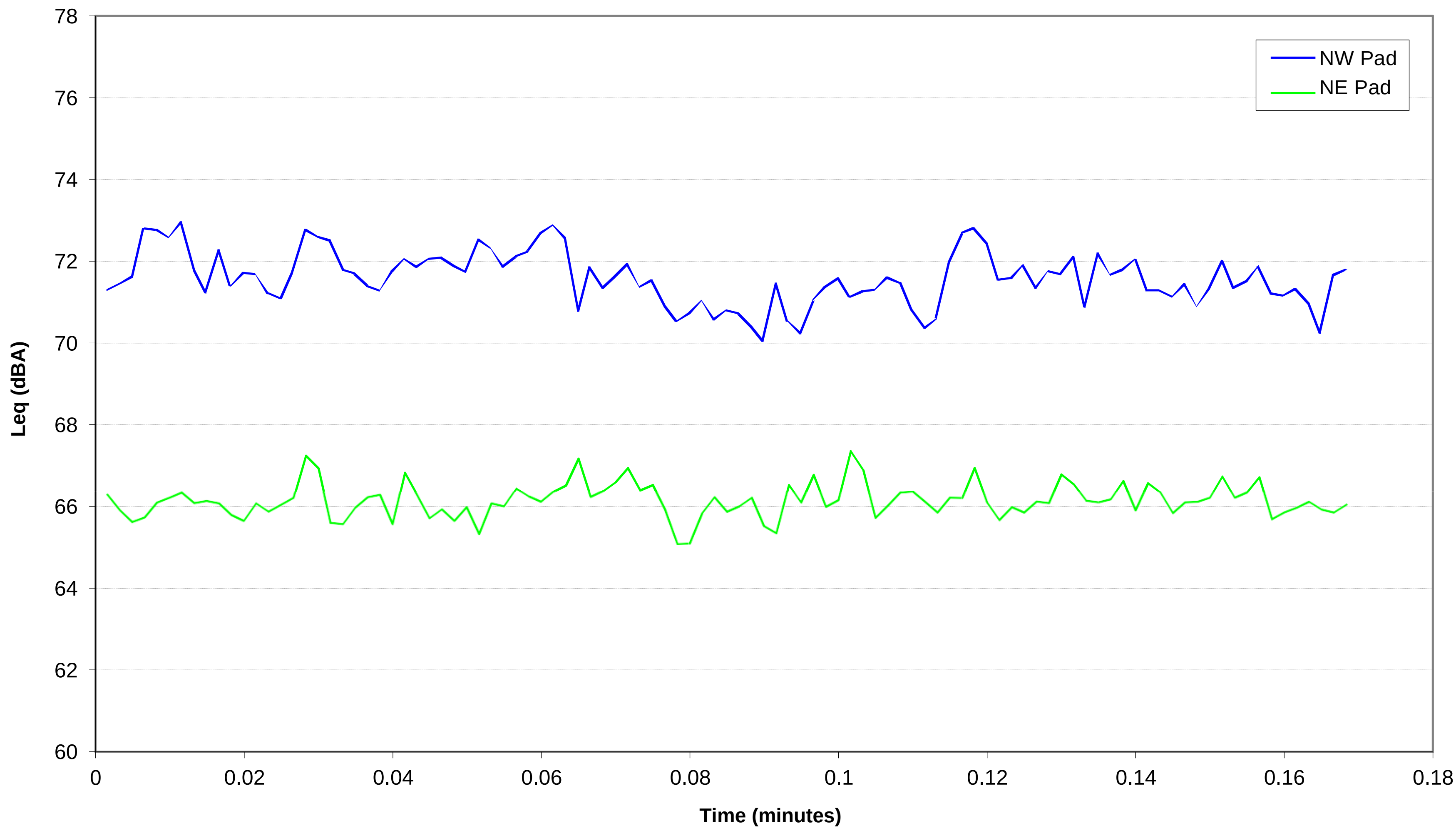
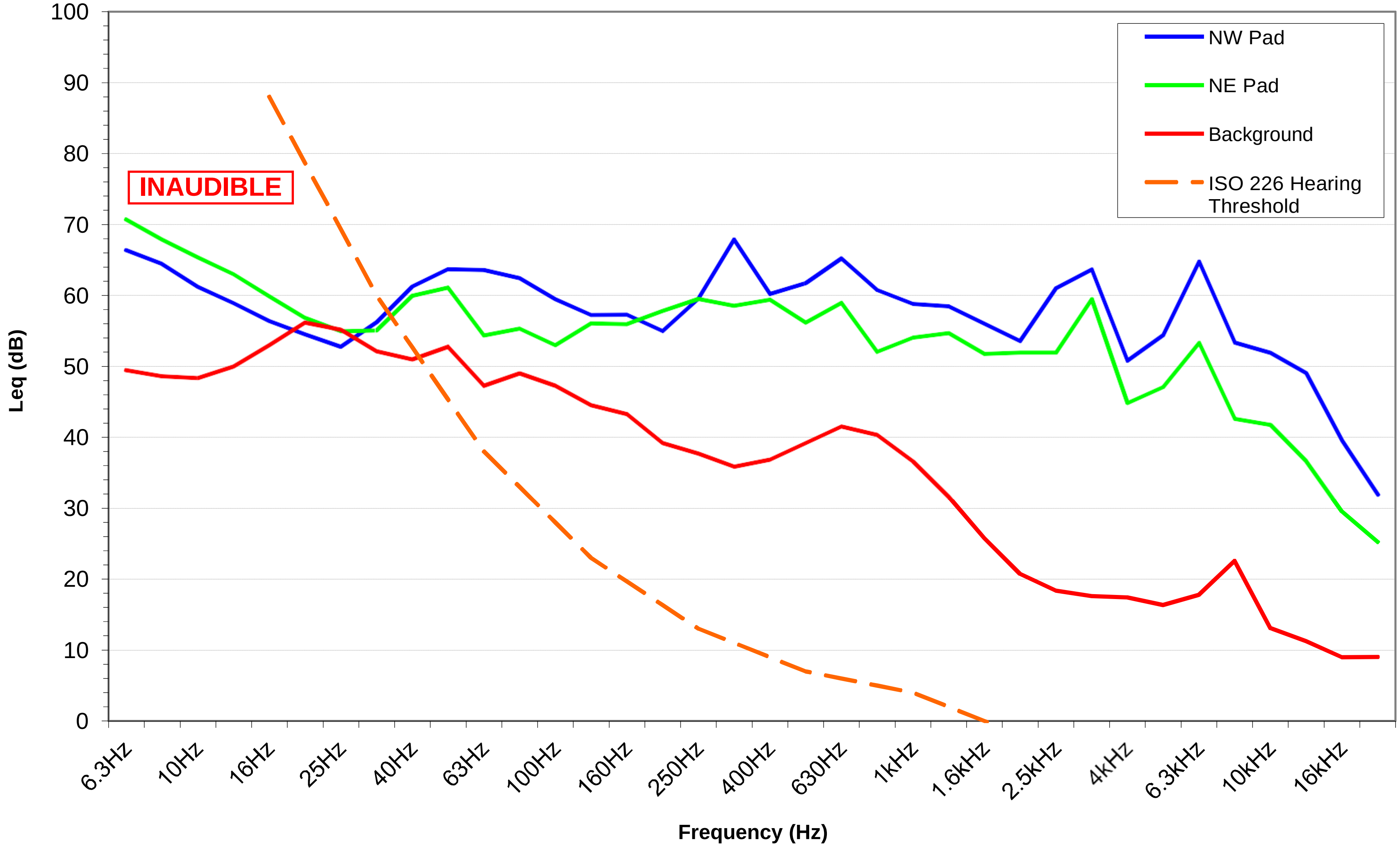


Figure 5. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1



3.2 Site 2 – Southborough Solar

Facility Location:	146 Cordaville Road, Southborough, MA
Facility Owner:	Southborough Solar, LLC
System Capacity:	1,000 kW
Power Output During Monitoring:	1,000 kW
No. & Size Inverters:	(2) 500-kW inverters
Date Measured:	Wednesday October 17, 2012
Cloud Cover:	5% (high, thin cirrus)
Winds:	Northwest 3-5 mph
Ground:	Wooded areas and wetlands surround the PV array, and a building is located to the south where the inverters are housed.
Background Sound:	Mean value L_{eq} of 53.1 dBA (range of 51.0 to 55.9 dBA). Mean value L_{90} of 49.6 dBA (range of 48.6 to 50.3 dBA). Sources included roadway traffic on Cordaville Road (to the west) and Route 9 (to the north) and natural sounds.
Background EMF:	None (< 0.2 mG and < 5 V/m).

The solar photovoltaic array is in a cleared area of land east of Cordaville Road in Southborough and the boundary of the array is fenced. The array is surrounded by wetlands and woods. The two inverters are not within the PV array; instead they are located on a single pad at the southeast corner of the building that lies south of the PV array. Measurements were made at the one equipment pad housing the two inverters. Due to the close proximity of wetlands to the fenced boundary for the PV array, it was not possible to obtain measurements 50 to 150 feet from the boundary. Instead, measurements were taken 50 to 150 feet set back from the property boundary of the site near where the inverter pad is located. The sound and EMF measurements made at Site 2 are summarized in Tables 4 through 6. Figures 6 and 7 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location (1X) for the equipment pad, while Figure 8 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

Sound Levels

Background sound levels varied over time and space across the site, depending on the distance from Cordaville Road, which carries heavy traffic volumes. Roadway traffic noise was the primary background sound source and higher levels were measured for locations on the west side of the site closer to Cordaville Road. Background sound levels varied over a range of 5 to 7 dBA. The background mean value L_{eq} and L_{90} levels were 53.1 dBA and 49.6 dBA, respectively. The inverters were inaudible at a distance of 50 feet outside of the site boundary. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the equipment pad (which holds two 500-kW inverters) were 48.1 to 60.8 dBA. Along the axis perpendicular to the inverter face, measured sound levels were 10 to 13 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels did not follow the expected hemispherical wave spreading law (approximately -6 dB per doubling of distance) and declined at a lower rate with increasing distance due to the relatively high background sound levels from nearby roadway traffic. At a distance of 150 feet, all inverter sounds were below background sound levels.

The time domain analysis presented in Figures 6 and 7 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 5 to 6 dBA. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. The rise and fall in inverter sound levels over several minutes is thought to be due to the passage of sheets of high thin cirrus clouds across the face of the sun during the measurements. The inverters registered full 500-kW capacity during both 10-minute monitoring periods.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 8) shows energy peaks in two 1/3-octave bands: 5,000 and 10,000 Hz. These high frequency peaks produce the characteristic “ringing noise” or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak is a first-harmonic tone (10 kHz being twice the frequency of 5 kHz). The tonal sound exhibited by Figure 8 is not, however, audible at distances of 50 to 150 feet beyond the site boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 8. The dashed line in Figure 8 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum declines smoothly with increasing frequency in the audible range except for a rise around 800 to 2,000 Hz caused by nearby roadway traffic noise.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the site boundary, are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels along the PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations 50 to 150 feet from the site boundary were not elevated above background levels (<0.2 mG).

Table 6 reveals that there are significant magnetic fields at locations a few feet from inverters, in the range of 200 to 500 mG. These levels drop back to background levels (<0.2 mG) at distances of 95 to 150 feet from the inverters. The variation of magnetic field with distance shown in Table 6 generally shows the field strength is proportional to the inverse cube of the distance from equipment.

TABLE 4

SOUND AND EMF LEVELS MEASURED AT SITE 2
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	53.3	54.4	0.2	< 5
South West Boundary	52.4	54.4	0.2	< 5
South East Boundary	48.3	50.8	0.4	< 5
North East Boundary	46.8	49.8	< 0.2	< 5
Background Mean Values	49.6	53.1	< 0.2	< 5
Set back 50 feet from Boundary	50.3	52.3	< 0.2	< 5
Set back 100 feet from Boundary	49.9	55.9	< 0.2	< 5
Set back 150 feet from Boundary	48.6	51.0	< 0.2	< 5

TABLE 5

SOUND LEVELS MEASURED AT SITE 2
EQUIPMENT PAD

Equipment Pad / Direction / Distance	L_{90} Level (dBA)	L_{eq} Level (dBA)
Parallel to Inverter Face / 10 feet	46.7	48.1
Parallel to Inverter Face / 20 feet	44.8	46.2
Parallel to Inverter Face / 30 feet	44.3	45.6
Parallel to Inverter Face / 95 feet*	44.0	45.6
Perpendicular to Inverter Face / 10 feet	59.9	60.8
Perpendicular to Inverter Face / 20 feet	57.3	58.7
Perpendicular to Inverter Face / 30 feet	53.4	54.5
Perpendicular to Inverter Face / 150 feet	46.2	47.5

*Measurements could not be taken at 150 feet parallel to inverter face because of the close proximity of wetlands. Instead, a measurement was made at the farthest practical distance in that direction at 95 feet.

TABLE 6

EMF LEVELS MEASURED AT SITE 2
EQUIPMENT PAD

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
Parallel to Inverter Face / 4 feet	200	< 5
Parallel to Inverter Face / 8 feet	10	< 5
Parallel to Inverter Face / 12 feet	0.8	< 5
Parallel to Inverter Face / 95 feet*	<0.2	< 5
Perpendicular to Inverter Face / 4 feet	500	< 5
Perpendicular to Inverter Face / 8 feet	25	< 5
Perpendicular to Inverter Face / 12 feet	4.5	< 5
Perpendicular to Inverter Face / 150 feet	<0.2	< 5

*Measurements could not be taken at 150 feet parallel to inverter face because of the close proximity of wetlands. Instead, a measurement was made at the farthest practical distance in that direction at 95 feet.

Figure 6. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #2

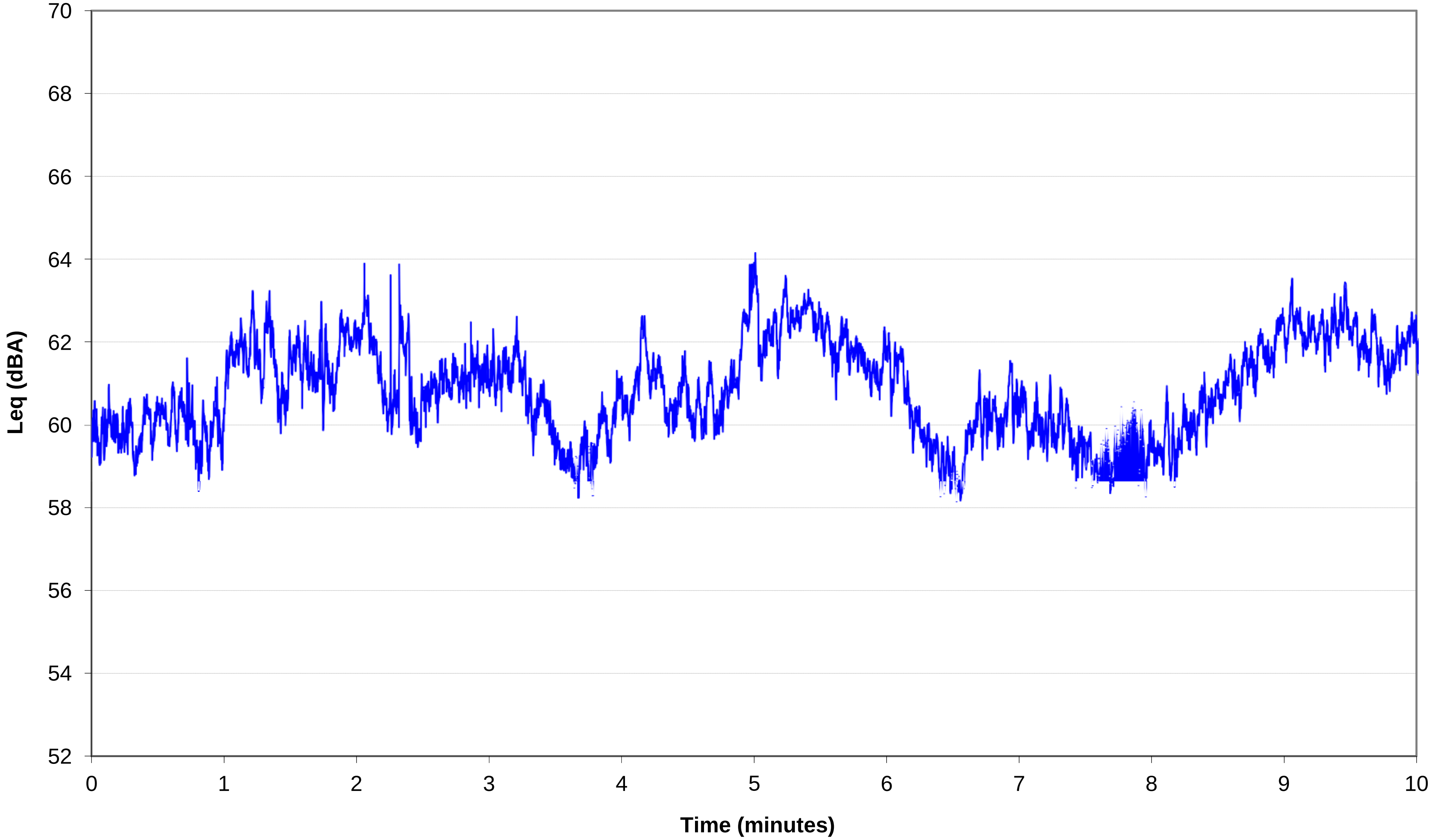


Figure 7. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #2 - First 10 Seconds of Measurements

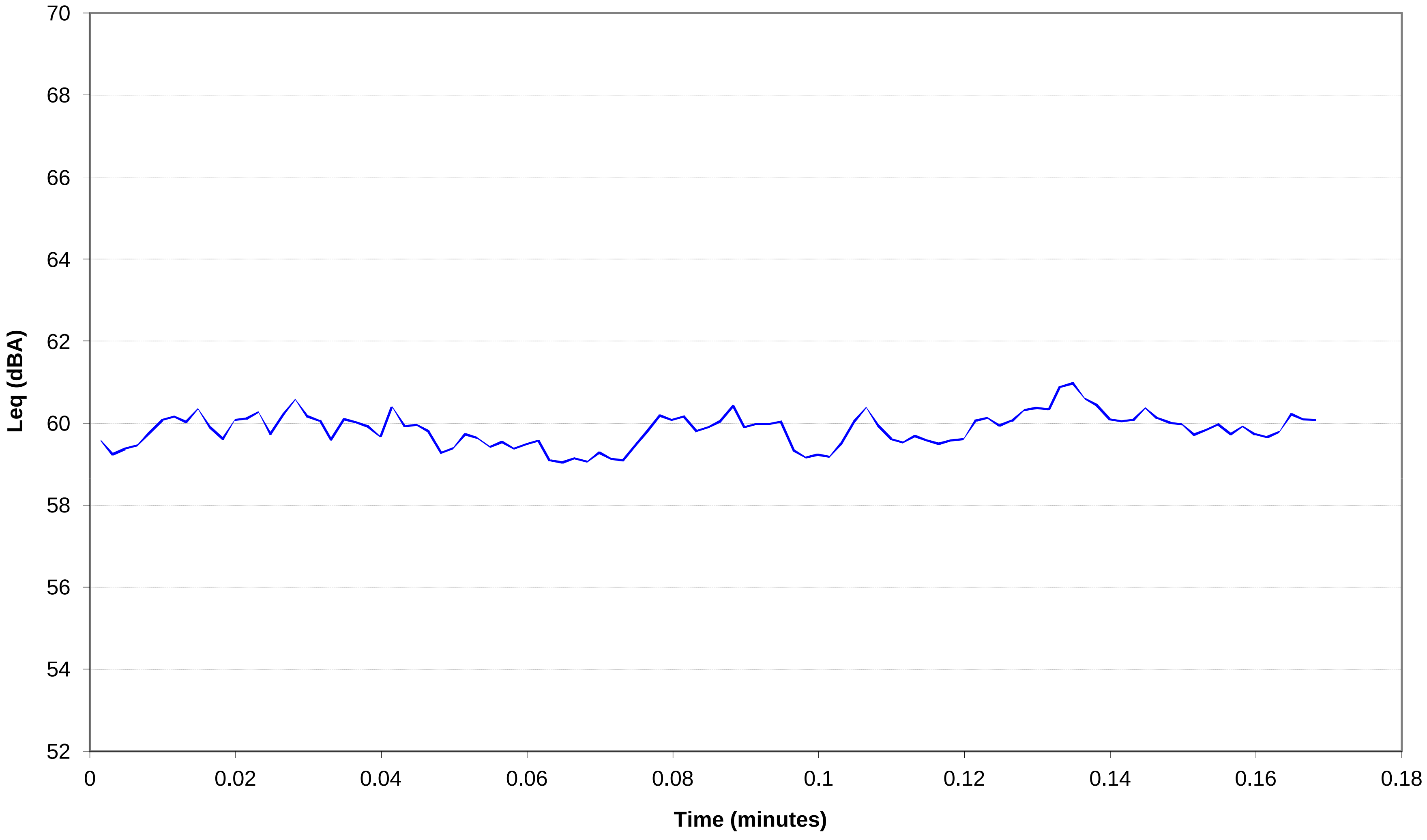
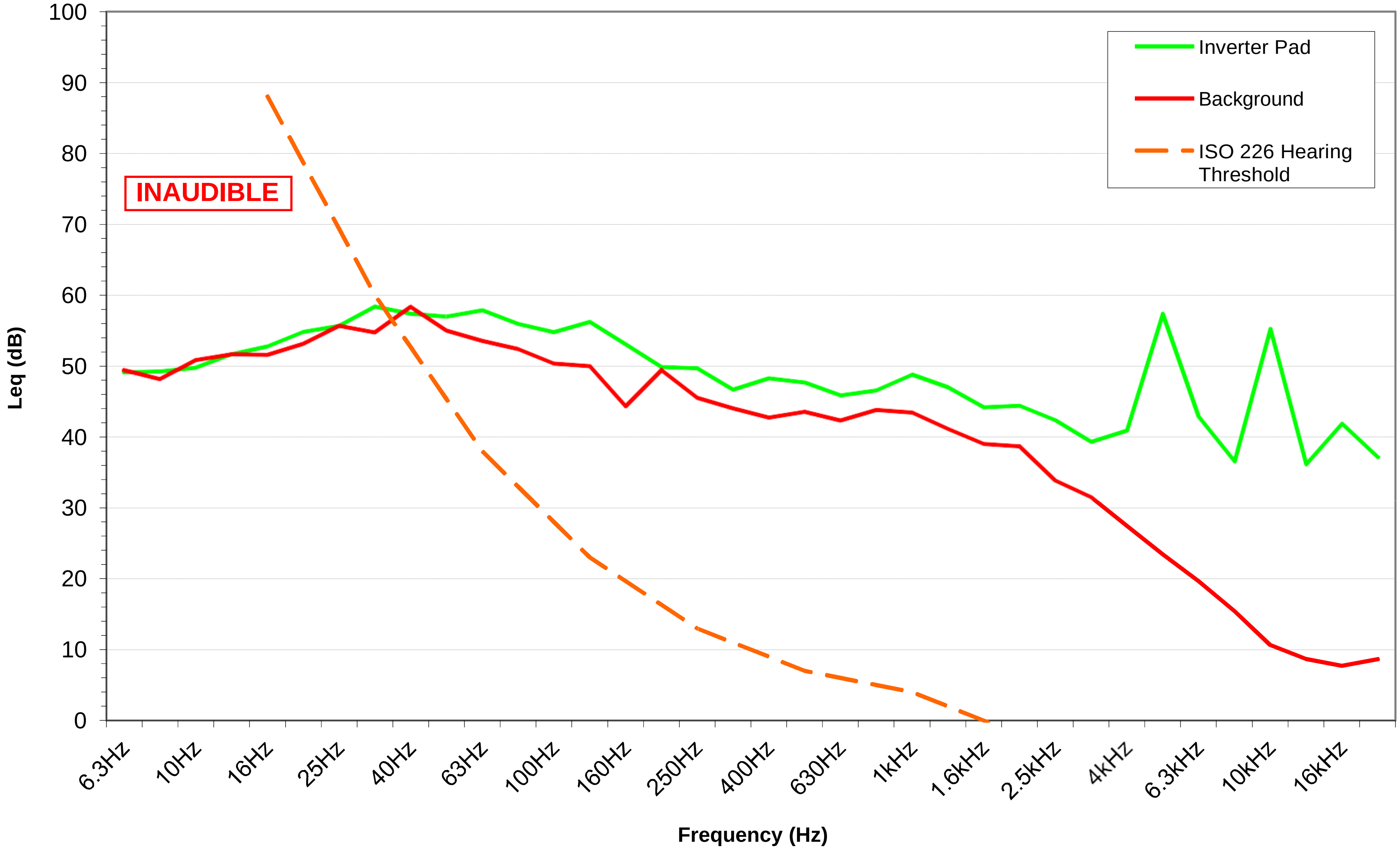


Figure 8. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad at Site #2



3.3 Site 3 – Norfolk Solar

Facility Location: 33 Medway Branch Road, Norfolk, MA
Facility Owner: Constellation Solar Massachusetts, LLC
System Capacity: 1,375 kW
Power Output During Monitoring: 1,200 to 1,375 kW
No. & Size Inverters: (2) 500-kW inverters and (1) 375-kW inverter
Date Measured: Monday October 22, 2012
Sky Cover: 10% (passing small cumulus clouds)
Winds: West 10-12 mph
Ground: One PV array sits high on top of the closed landfill with grass cover and no surrounding vegetation. The other, larger PV array is in a wooded area on relatively flat ground. Measurements were made at the larger PV array.
Background Sound: Mean value L_{eq} of 45.3 dBA (range of 43.1 to 47.5 dBA). Mean value L_{90} of 42.5 dBA (range of 42.1 to 43.2 dBA). Sources included distant traffic noise and natural sounds.
Background EMF: None (< 0.2 mG and < 5 V/m).

There are two solar photovoltaic arrays on the land of the Town of the Norfolk Department of Public Works. One array sits on top of a capped landfill and has a single equipment pad with one inverter. The second, and larger, array is in a cleared flat area east of the capped landfill and has a single equipment pad housing two inverters. The boundaries of the PV arrays are fenced. The surrounding area has only grass cover or low vegetation. Measurements were made at the larger PV array and at the equipment pad housing two inverters with a capacity of 875 kW. The sound and EMF measurements made at Site 3 are summarized in Tables 7 through 9. Figures 9 and 10 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location (1X) for the equipment pad, while Figure 11 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

Sound Levels

Background sound levels were fairly constant across the site and distant roadway traffic was the primary background sound source. The background mean value L_{eq} and L_{90} levels were 45.3 dBA and 42.5 dBA, respectively. The PV array was inaudible outside of the fenced boundary except at the South East boundary location where a faint inverter hum could be heard. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the equipment pad (which holds two inverters) were 54.8 to 60.9 dBA. Along the axis perpendicular to the inverter face measured sound levels were 6 to 7 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels generally followed the expected hemispherical wave spreading law (approximately -6 dB per doubling of distance). At a distance of 150 feet, all inverter sounds were below background sound levels.

The time domain analysis presented in Figures 9 and 10 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 3 to 4 dBA. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. Between 7 and 9 minutes into the 10-minute measurement, clouds passed over the face of the sun, power production dropped, and the inverter cooling fans turned off for a brief period, as shown by the abrupt 4 dBA drop in sound level in Figure 9.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 11) shows energy peaks in four 1/3-octave bands: 63, 125, 5,000 and 10,000 Hz. The high frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak in each pair is a first-harmonic tone (10 kHz being twice the frequency of 5 kHz). The tonal sound exhibited by Figure 11 is not, however, audible at distances of 50 to 150 feet beyond the site boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 11. The dashed line in Figure 11 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum declines smoothly with increasing frequency in the audible range except for a slight rise around 800 to 2,000 Hz caused by distant roadway traffic noise.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the site boundary, are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels along the PV array boundary were in the very low range, at or below 0.2 mG. Magnetic field levels at the locations 50 to 150 feet from the site boundary were not elevated above background levels (<0.2 mG).

Table 9 reveals that there are significant magnetic fields at locations a few feet from inverters, in the range of 150 to 500 mG. These levels drop back to levels of 0.4 mG in the perpendicular direction and to background levels (<0.2 mG) in the parallel direction at 150 feet from the inverters. The variation of magnetic field with distance shown in Table 9 generally shows the field strength is proportional to the inverse cube of the distance from equipment.

TABLE 7

SOUND AND EMF LEVELS MEASURED AT SITE 3
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	46.2	48.3	< 0.2	< 5
South West Boundary	48.9	50.6	< 0.2	< 5
South East Boundary	43.3	44.3	0.2	< 5
North East Boundary	43.9	46.1	< 0.2	< 5
Background Mean Values	42.5	45.3	< 0.2	< 5
Set back 50 feet from Boundary	43.2	47.5	< 0.2	< 5
Set back 100 feet from Boundary	42.2	45.4	< 0.2	< 5
Set back 150 feet from Boundary	42.1	43.1	< 0.2	< 5

TABLE 8

SOUND LEVELS MEASURED AT SITE 3
EQUIPMENT PAD

Equipment Pad / Direction / Distance	**L_{90} Level (dBA)**	**L_{eq} Level (dBA)**
Perpendicular to Inverter Face / 10 feet	59.7	60.9
Perpendicular to Inverter Face / 20 feet	57.3	58.6
Perpendicular to Inverter Face / 30 feet	49.4	50.1
Perpendicular to Inverter Face / 150 feet	43.9	47.0
Parallel to Inverter Face / 10 feet	53.9	54.8
Parallel to Inverter Face / 20 feet	50.6	51.3
Parallel to Inverter Face / 30 feet	45.5	48.0
Parallel to Inverter Face / 150 feet	41.8	43.7

TABLE 9

EMF LEVELS MEASURED AT SITE 3
EQUIPMENT PAD

Equipment Pad / Direction / Distance	**Magnetic Field (mG)**	**Electric Field (V/m)**
Parallel to Inverter Face / 3 feet	150	< 5
Parallel to Inverter Face / 6 feet	10	< 5
Parallel to Inverter Face / 9 feet	5	< 5
Parallel to Inverter Face / 150 feet	< 0.2	< 5
Perpendicular to Inverter Face / 3 feet	500	< 5
Perpendicular to Inverter Face / 6 feet	200	< 5
Perpendicular to Inverter Face / 9 feet	80	< 5
Perpendicular to Inverter Face / 150 feet	0.4	< 5

Figure 9. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #3

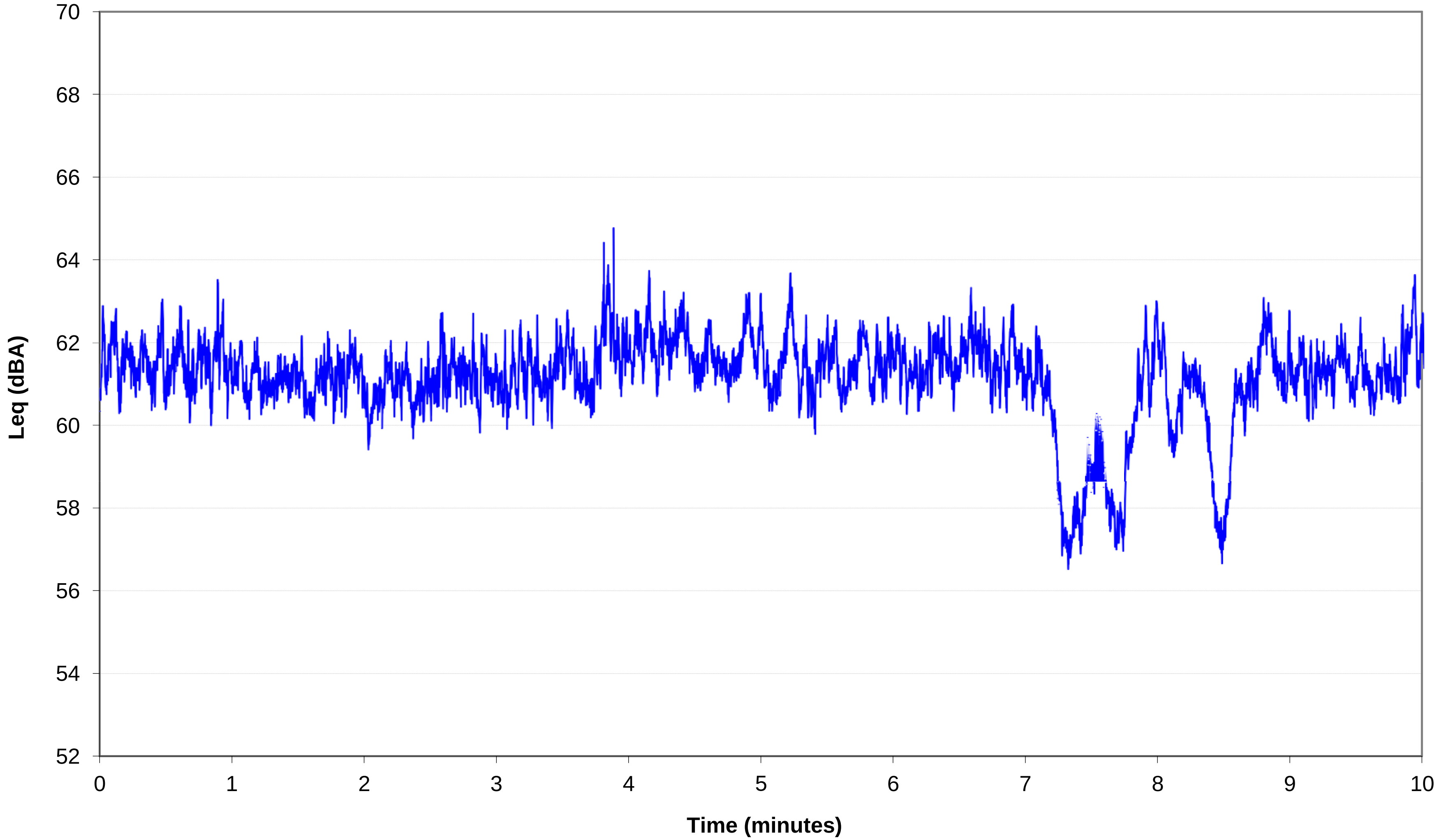


Figure 10. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #3 - First 10 Seconds of Measurements

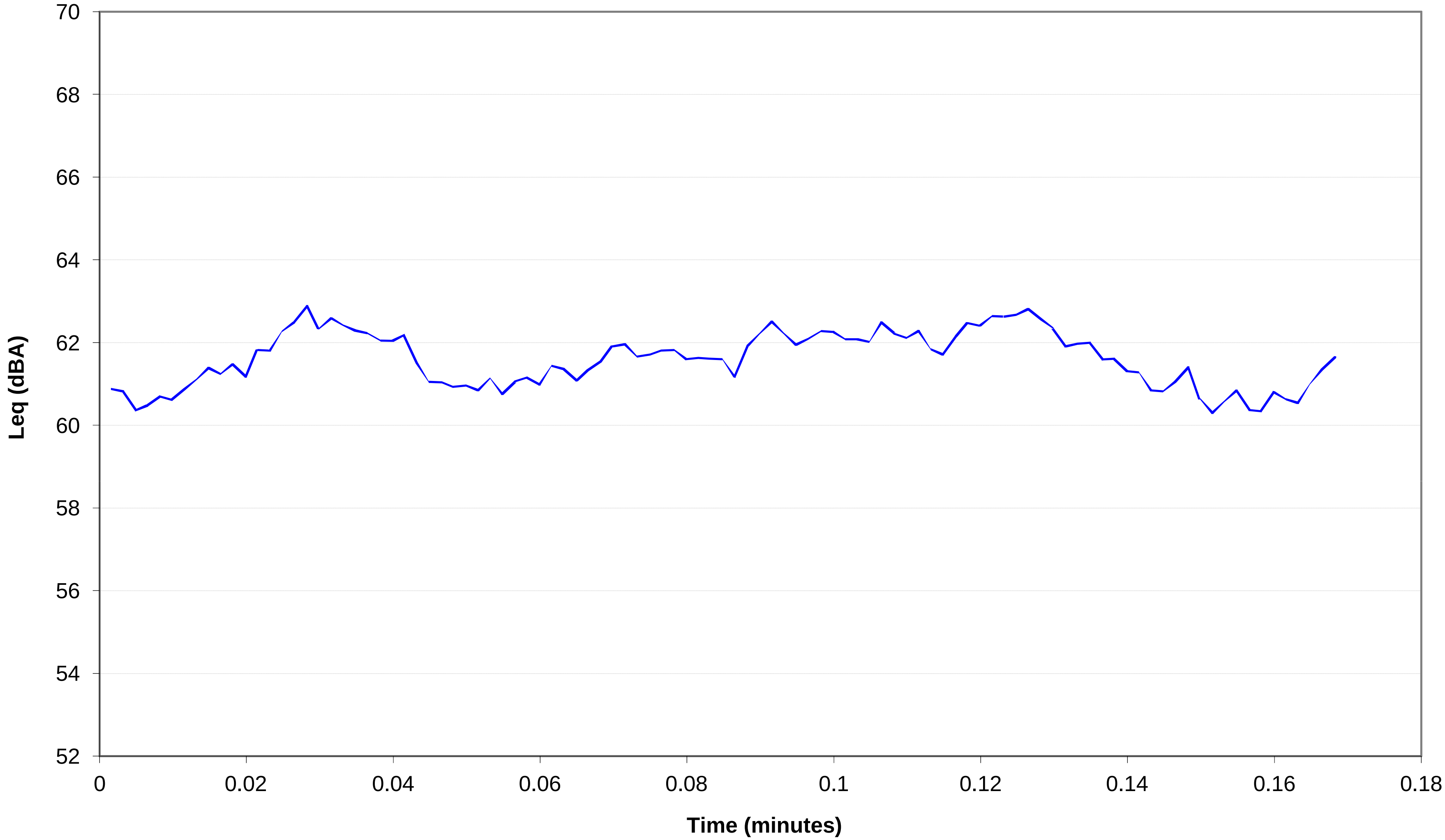
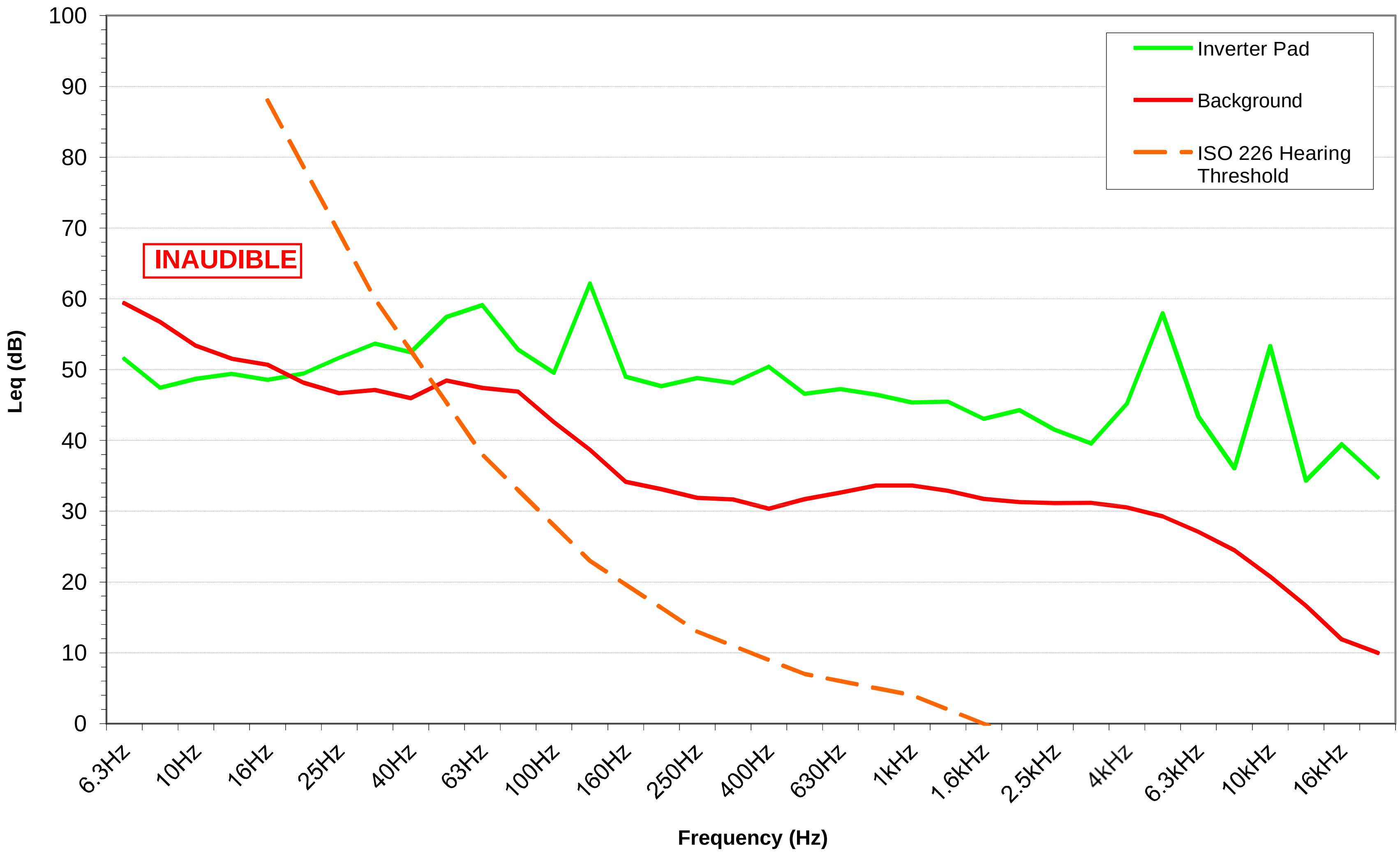


Figure 11. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad at Site #3



3.4 Site 4 – Residential Solar at Mass. Audubon Society in Sharon

Facility Location:	Moose Hill Sanctuary, 293 Moose Hill Road, Sharon, MA
Facility Owner:	Massachusetts Audubon Society
System Capacity:	8.6 kW
Power Output During Monitoring:	4.2 kW
No. & Size Inverters:	(1) 5-kW inverter and (1) 3.6-kW inverter
Date Measured:	Friday October 26, 2012
Sky Cover:	50% (scattered clouds)
Winds:	Northwest 0-3 mph
Ground:	(42) Evergreen solar panels are mounted on the pitched roof of the two-story building and face south. The ground around the site is cleared and opens to the south with surrounding woods at a distance.
Background EMF:	None in occupied rooms (< 0.2 mG and < 5 V/m). In the basement storage space where the inverters were housed, a background magnetic field of 2 mG was present and the background electric field was < 5 V/m.

EMF measurements were made inside the headquarters building of the Massachusetts Audubon Moose Hill Sanctuary. No sound measurements were made for this residential sized solar installation. The EMF measurements were made in rooms on the second floor of the building, the closest locations occupants have to the roof-mounted panels. Measurements were also made at the inverters inside the basement of the building, in a space not readily accessible to the public. The EMF measurements made at Site 4 are summarized in Tables 10 and 11.

Electric Fields

Electric field levels in the rooms on the top floor, nearest the roof-mounted solar panels are not elevated above background levels (< 5 V/m). In the basement, electric fields near the inverters (3 feet) are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels in the rooms on the top floor, nearest the roof-mounted solar panels were in the very low range of 0.2 to 1.4 mG. Table 11 reveals that there are low-level magnetic fields at locations a few feet from inverters, around 6 to 10 mG. These levels dropped back to a floor of 2 mG at a distance of 6 to 9 feet from the inverters. Nearby electrical lines and other equipment in the basement created a background of 2 mG in the space where the inverters were housed.

TABLE 10

EMF LEVELS MEASURED INSIDE THE RESIDENTIAL BUILDING, TOP FLOOR AT SITE 4

Boundary Location	Magnetic Field (mG)	Electric Field (V/m)
North West Room	0.9	< 5
South West Room	1.4	< 5
South East Room	0.2	< 5
North East Room	0.5	< 5

TABLE 11

EMF LEVELS MEASURED INSIDE THE RESIDENTIAL BUILDING, BASEMENT AT SITE 4

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
Parallel to Inverter Face / 3 feet	10	< 5
Parallel to Inverter Face / 6 feet	6	< 5
Parallel to Inverter Face / 9 feet	2	< 5
Parallel to Inverter Face / 15 feet	2	< 5
Perpendicular to Inverter Face / 3 feet	6	< 5
Perpendicular to Inverter Face / 6 feet	2	< 5
Perpendicular to Inverter Face / 9 feet	2	< 5
Perpendicular to Inverter Face / 15 feet	2	< 5

4.0 CONCLUSIONS

Sound pressure level and electromagnetic field (EMF) measurements were made at three utility-scale PV arrays with a capacity range of 1,000 to 3,500 kW under a full-load condition with sunny skies and the sun at approximately 40^{o} azimuth. Measurements were taken at set distances from the inverter pads and along the fenced boundary of the PV array. Measurements were also made at set distances back from the boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of sound levels from the equipment.

EMF Measurements were also made at one residential[6] PV installation with a capacity of 8.6 kW under a partial-load condition. PV array operation is related to the intensity of solar insolation. Less sunshine results in lower sound and EMF levels from the equipment, and no sound or EMF is produced at night when no power is produced. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

Sound Levels

At the utility scale sites, sound levels along the fenced boundary of the PV arrays were generally at background levels, though a faint inverter hum could be heard at some locations along the boundary. Any sound from the PV array and equipment was inaudible and sound levels are at background levels at set back distances of 50 to 150 feet from the boundary.

Average L_{eq} sound levels at a distance of 10 feet from the inverter face varied over the range of 48 dBA to 61 dBA for Site 2 and Site 3 Inverters[7], and were higher in the range of 59 to 72 dBA for Site 1 Inverters. Along the axis perpendicular to the plane of the inverter face and at distances of 10 to 30 feet, sound levels were 4 to 13 dBA higher compared to levels at the same distance along the axis parallel to the plane of the inverter face. At a distance of 150 feet from the inverter pad, sound levels

[6] Only EMF measurements were made at the residential site.

[7] The same make of inverters were used at Sites 2 and 3.

approached background levels. Sound level measurements generally followed the hemispherical wave spreading law (-6 dB per doubling of distance).

The time domain analysis reveals that 0.1-second L_{eq} sound levels at a distance of 10 feet from an inverter pad generally varied over a range of 2 to 6 dBA, and no recurring pattern in the rise and fall of the inverter sound levels with time was detected. The passage of clouds across the face of the sun caused cooling fans in the inverters to briefly turn off and sound levels to drop 4 dBA.

The 1/3-octave band frequency spectrum of equipment sound at the close distance of 10 feet shows energy peaks in several mid-frequency and high-frequency bands, depending on the inverter model. Tonal sound was found to occur in harmonic pairs: 63/125 Hz; 315/630 Hz; 3,150/6,300 Hz; and 5,000/10,000 Hz. The high frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The tonal sound was not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum. All low-frequency sound from the inverters below 40 Hz is inaudible, at all distances.

Electric Fields

The International Commission on Non-Ionizing Radiation Protection has a recommended exposure limit of 4,200 V/m for the general public. At the utility scale sites, electric field levels along the fenced PV array boundary, and at the locations set back 50 to 150 feet from the boundary, were not elevated above background levels (< 5 V/m). Electric fields near the inverters were also not elevated above background levels (< 5 V/m).

At the residential site, indoor electric fields in the rooms closest to the roof-mounted panels and at locations near the inverters were not elevated above background levels (< 5 V/m).

Magnetic Fields

The International Commission on Non-Ionizing Radiation Protection has a recommended exposure limit of 833 mG for the general public. At the utility scale sites, magnetic field levels along the fenced PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations

50 to 150 feet from the array boundary were not elevated above background levels (<0.2 mG). There are significant magnetic fields at locations a few feet from inverters, in the range of 150 to 500 mG. At a distance of 150 feet from these utility-scale inverters, these fields drop back to very low levels of 0.5 mG or less, and in many cases to background levels (<0.2 mG). The variation of magnetic field with distance generally shows the field strength is proportional to the inverse cube of the distance from equipment.

At the residential site, indoor magnetic field levels in the rooms closest to the roof-mounted panels were in the low range of 0.2 to 1.4 mG. There are low-level magnetic fields at locations a few feet from the inverters, in the range of 6 to 10 mG. At a distance of no more than 9 feet from the inverters, these fields dropped back to the background level at the residential site of 2 mG. Due to the relatively high background level in the residential site basement where the inverters were housed, the relationship of magnetic field strength to distance from the inverters could not be discerned.

APPENDIX A

ACOUSTIC TERMS AND METRICS

All sounds originate with a source – a human voice, vehicles on a roadway, or an airplane overhead. The sound energy moves from the source to a person's ears as sound waves, which are minute variations in air pressure. The loudness of a sound depends on the **sound pressure level**[8], which has units of decibel (dB). The **decibel scale** is logarithmic to accommodate the wide range of sound intensities to which the human ear is subjected. On this scale, the quietest sound we can hear is 0 dB, while the loudest is 120 dB. Every 10-dB increase is perceived as a doubling of loudness. Most sounds we hear in our daily lives have sound pressure levels in the range of 30 dB to 90 dB.

A property of the decibel scale is that the numerical values of two separate sounds do not directly add. For example, if a sound of 70 dB is added to another sound of 70 dB, the total is only a 3-decibel increase (or 73 dB) on the decibel scale, not a doubling to 140 dB. In terms of sound perception, 3 dB is the minimum change most people can detect. In terms of the human perception of sound, a halving or doubling of loudness requires changes in the sound pressure level of about 10 dB; 3 dB is the minimum perceptible change for **broadband** sounds, i.e. sounds that include all frequencies. Typical sound levels associated with various activities and environments are presented in Table A-1. The existing sound levels at a PV project site are determined primarily by the proximity to roads and highways, the source of traffic noise. Sound exposure in a community is commonly expressed in terms of the **A-weighted sound level (dBA)**; A-weighting approximates the frequency response of the human ear and correlates well with people's perception of loudness.

The level of most sounds change from moment to moment. Some are sharp impulses lasting one second or less, while others rise and fall over much longer periods of time. There are various measures of sound pressure designed for different purposes. The equivalent sound level $\mathbf{L_{eq}}$ is the steady-state sound level over a period of time that has the same acoustic energy as the fluctuating sounds that actually occurred during that same period. It is commonly referred to as the energy-average sound

[8] The sound pressure level is defined as $20*\log_{10}(P/P_o)$ where P is the sound pressure and P_o is the reference pressure of 20 micro-Pascals (20 μPa), which by definition corresponds to 0 dB.

level and it includes in its measure all of the sound we hear. EPA has determined that the $\mathbf{L_{eq}}$ average sound level correlates best with how people perceive and react to sound.[9]

To establish the background sound level in an area, the $\mathbf{L_{90}}$ metric, which is the sound level exceeded 90% of the time, is typically used. The $\mathbf{L_{90}}$ can be thought of as the level representing the quietest 10% of any time interval. The $\mathbf{L_{90}}$ is a broadband sound pressure measure. By definition, the $\mathbf{L_{90}}$ metric will filter out brief, loud sounds, such as intermittent traffic on a nearby roadway.

Sound pressure level measurements typically include an analysis of the sound spectrum into its various frequency components to determine tonal characteristics. The unit of frequency is **Hertz (Hz)**, measuring the cycles per second of the sound pressure waves. In the physiology of human hearing, every octave jump of a tone corresponds to a doubling of the sound frequency in Hz. For example, Middle-C on a piano has a frequency of approximately 260 Hz. High-C, one octave above, has a frequency of approximately 520 Hz. The hearing range for most people is 20 Hz to 20,000 Hz. In acoustic studies, the sound spectrum is divided into **octave bands** with center frequencies that are an octave apart, or 1/3-octave bands with center frequencies that are 1/3 of an octave apart. There are 11 whole octave bands centered in the audible range from 20 to 20,000 Hz. For the extended frequency range of 6.3 Hz to 20,000 Hz used in this study, there are 36 1/3-octave bands.

Low-frequency sound generally refers to sounds below 250 Hz in frequency, which is close to the tone of Middle-C on a piano. **Infrasound** is low-frequency sound at frequencies below 20 Hz, a sound wave oscillating only 20 cycles per second. For comparison, the lowest key on a piano produces a tone of 28 Hz, and human speech is in the range of 500 to 2,000 Hz. The hearing threshold for infrasound at 16 Hz is 90 decibels (dB).[10] We are enveloped in naturally occurring infrasound, which is inaudible. Infrasound is always present in the outdoor environment due to sounds generated by air turbulence, shoreline waves, motor vehicle traffic and distant aircraft.

[9] U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," Publication EPA-550/9-74-004.

[10] International Standards Organization, ISO 226:2003.

TABLE A-1

VARIOUS INDOOR AND OUTDOOR SOUND LEVELS

Outdoor Sound Levels	Sound Pressure (μPa)		Sound Level (dBA)	Indoor Sound Levels
	6,324,555	-	110	Rock Band at 5 m
Jet Over-Flight at 300 m		-	105	
	2,000,000	-	100	Inside New York Subway Train
Gas Lawn Mower at 1 m		-	95	
	632,456	-	90	Food Blender at 1 m
Diesel Truck at 15 m		-	85	
Noisy Urban Area--Daytime	200,000	-	80	Garbage Disposal at 1 m
		-	75	Shouting at 1 m
Gas Lawn Mower at 30 m	63,246	-	70	Vacuum Cleaner at 3 m
Suburban Commercial Area		-	65	Normal Speech at 1 m
Quiet Urban Area -- Daytime	20,000	-	60	
		-	55	Quiet Conversation at 1m
Quiet Urban Area--Nighttime	6,325	-	50	Dishwasher Next Room
		-	45	
Suburban Area--Nighttime	2,000	-	40	Empty Theater or Library
		-	35	
Rural Area--Nighttime	632	-	30	Quiet Bedroom at Night
		-	25	Empty Concert Hall
Rustling Leaves	200	-	20	Average Whisper
		-	15	Broadcast and Recording Studios
	63	-	10	
		-	5	Human Breathing
Reference Pressure Level	20	-	0	Threshold of Hearing

Notes:
μPa - Micropascals describe sound pressure levels (force/area).
dBA - A-weighted decibels describe sound pressure on a logarithmic scale with respect to 20 μPa.

APPENDIX B

EMF TERMS AND METRICS

An electromagnetic field (**EMF**) is the combination of an **electric field** and a **magnetic field**. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents). From a classical physics perspective, the electromagnetic field can be regarded as a smooth, continuous field, propagated in a wavelike manner. From the perspective of quantum field theory, the field is seen as quantized, being composed of individual particles (photons).

EMFs are present everywhere in our environment but are invisible to the human eye. For example, electric fields are produced by the local build-up of electric charges in the atmosphere associated with thunderstorms, and the earth's magnetic field causes a compass needle to orient in a North-South direction and is used for navigation. Besides natural sources, the electromagnetic spectrum also includes fields generated by man-made sources. For example, the electricity that comes out of every power socket has associated low frequency EMFs. A photovoltaic (PV) project generates low-frequency EMFs from inverters (that convert DC-current to AC-current), transformers (that step-up the PV project voltage), and current-carrying cables. The EMFs from PV project components are classified as "non-ionizing radiation," because the electromagnetic waves have low-energy quanta incapable of breaking chemical bonds in objects through which they pass.

The strength of the **electric field** is measured in volts per meter (**V/m**). Any electrical wire that is charged will produce an associated electric field. This field exists even when there is no current flowing. The higher the voltage, the stronger the electric field at a given distance from the wire. Magnetic fields arise from the motion of electric charges. The strength of the **magnetic field** is measured by the magnetic flux density in milli-Gauss (**mG**). In contrast to electric fields, a magnetic field is only produced once a device is switched on and current flows. The higher the current, the greater the strength of the magnetic field produced at a given distance. EMFs are strongest close to a source, and their strength rapidly diminishes with distance from it. Field strength is generally proportional to the inverse cube of the distance.

Typical household fixtures and appliances produce both types of fields. For example, at a distance of one foot from a fluorescent light, electric and magnetic fields of 50 V/m and 2 mG, respectively, are measured. At a distance of 1 inch from the power cord for an operating personal computer, fields of 40 V/m and 1 mG, respectively, are detected.

There are no federal, State or local regulatory exposure limits for electric or magnetic fields that apply to solar photovoltaic arrays. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has recommended exposure limits of 4,200 V/m and 833 mG for the general public. ICNIRP is an organization of 15,000 scientists in 40 nations who specialize in radiation protection, and their recommendations are routinely used in EMF exposure studies.

Exhibit E

A Study of Hazardous Glare Potential to Aviators from Utility Scale Flat Plate Photovoltaic Systems

International Scholarly Research Network
ISRN Renewable Energy
Volume 2011, Article ID 651857, 6 pages
doi:10.5402/2011/651857

Research Article

A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems

Evan Riley and Scott Olson

Black & Veatch Corporation, Energy Division, 650 California Street, Fifth Floor, San Francisco, CA 94108, USA

Correspondence should be addressed to Evan Riley, rileye@bv.com

Received 15 August 2011; Accepted 17 September 2011

Academic Editors: E. R. Bandala, S. Dai, S. S. Kalligeros, and A. Stoppato

The potential flash glare a pilot could experience from a proposed 25-degree fixed-tilt flat-plate polycrystalline PV system located outside of Las Vegas, Nevada, was modeled for the purpose of hazard quantification. Hourly insolation data measured via satellite for the years 1998 to 2004 was used to perform the modeling. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image potential caused by smooth water. The results show that the potential for hazardous glare from flat-plate PV systems is similar to that of smooth water and not expected to be a hazard to air navigation.

1. Introduction

Before construction of utility scale photovoltaic (PV) power plants near airports or within known flight corridors in the United States, the Federal Aviation Administration (FAA) requires that the glare from the proposed plant not be a hazard to navigable airspace [1]. The purpose of this paper is to demonstrate that glare from flat-plate PV power plants is similar to that of water and therefore does not pose a hazard to navigable airspace.

This was done by calculating the glare potential from a theoretical flat-plate PV power plant located near Las Vegas, Nevada, and comparing that glare to the glare potential of smooth water.

To estimate potential glare from flat surfaces, a model developed which used conservative assumptions. This model is a generalization of work done by Ho et al. [1]. The model calculated glare hourly from 1998 to 2004 to find the times when the possibility for glare would be the greatest. The potential for after-image (hazardous glare) was then compared to the potential for hazardous glare from smooth water which pilots often view while on approach to land.

2. Method

A review of published literature on modeling glare was conducted. The effects of glare on humans has been quantified by Metcalf and Horn [2], Saur and Dobrash [3], Severin et al. [4], and Sliney and Freasier [5]. In other studies Brumleve [6], Chiabrando et al. [7], and Ho et al. [1] developed mathematical methods to quantify the potential danger of glare causing flash blindness. Flash blindness is defined by Ho as a "temporary disability or distraction" that can cause an after-image and is understood to be comparable to what a human experiences when viewing the flash of a camera.

Ho explains in detail various methods for modeling glare from concentrating solar systems which use mirrors and lenses to concentrate light onto a central receiver. This technology is different than flat-plate PV modules which directly convert solar energy to electricity. However, the after-image estimation method Ho outlines for concentrating solar systems is easily generalized to flat-plate PV modules. The flow diagram in Figure 1 shows the general method implemented to translate solar radiation to the after-image potential caused by energy received on an observer's retina.

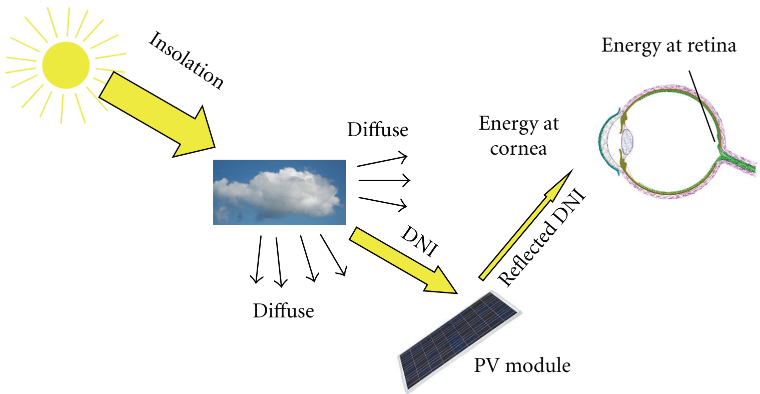


Figure 1: Energy flow diagram.

The subsections below provide more detail for each step of the process.

2.1. Insolation. The SUNY-Perez Satellite dataset was used for modeling glare. The National Renewable Energy Laboratory (NREL) compiled this dataset for the years 1998 to 2005 on an hourly basis for a 10×10 km nationwide grid.

Solar radiation in the visible spectrum can be broken up into two primary components, diffuse and direct. Diffuse radiation is defined as radiation that has been scattered by the atmosphere. Direct radiation, also commonly referred to as beam, is radiation which moves from the source to the observer via the shortest distance possible without scattering. For example, on a heavily overcast day when the sun is highest in the sky (solar noon), it is probable that all insolation is diffuse. On a clear day at solar noon, most of the insolation reaching earth's surface would be direct. Direct radiation is the component of solar radiation that causes visible glare from flat plate PV systems.

2.2. PV Module. The next step in the modeling process was to quantify the amount of visible radiation would be reflected off of a PV module for every hour from 1998 to 2004. The year 2005 was omitted for computational reasons. This was done by multiplying the power (Watts per square centimeter, or W/cm^2) of direct radiation with the reflectivity of the PV module at the average incidence angle for each hour evaluated.

Incidence angle is defined as the angle between the direct component of insolation and a ray perpendicular to the module. If the incidence angle is zero, the angle between the surface of the module and the direct component of radiation is 90°. The reflectance at 633 nm of a polycrystalline silicon (p-Si) PV module is a function of the incidence angle as seen below in Figure 2 developed by Parretta et al. [8]. This reflectance as a function of incidence angle was to determine how much of the direct insolation in the visible spectrum would be reflected off of the PV module and thus reach the observer.

The data shown above is for a glass encapsulated p-Si solar cell. The use of this data is a conservative assumption as the glass used to encapsulate the cell was not solar glass and no antireflective coating applied to the p-Si cell. Actual p-Si modules would likely have lower reflectance values as textured glass, and antireflective coatings are often used to reduce reflected irradiance and increase module efficiency.

The power of the reflected direct radiation was calculated hourly from 1998 to 2004 using the reflectivity in Figure 2, satellite data from NREL, and established sun position equations. The use of hourly data allows quantification of how the power of the reflected direct radiation will vary as the sun moves across the sky.

2.3. Energy at the Cornea. An assumption was made that the power of the direct radiation reflected off of the PV module was equal to the power incident on the cornea of the pilot. This is a conservative assumption as it ignores atmospheric attenuation, refraction, and further reflection. While it is likely that there will be energy diffusion or absorption due to the atmosphere, cockpit glass, or shielding, these effects were ignored during this initial estimation. Later calculations took these potential mitigation efforts into account, as can be seen in Figure 7.

2.4. Retinal Irradiance. The last step in the modeling process was to calculate retinal irradiance hourly from 1998 to 2004. Retinal irradiance can be calculated us a derivation provided by Sliney [9] from the energy incident on the cornea as

$$E_r = E_c \left(\frac{d_p}{f\omega} \right)^2 \tau, \qquad (1)$$

where E_r is retinal irradiance [W/cm^2], E_c is irradiance at a plane in front of the cornea [W/cm^2], f is the focal length of the eye ($\sim$0.17 cm), d_p is the diameter of the human pupil adjusted to sunlight ($\sim$0.2 cm), ω is the subtended angle of the image (or apparent size of the image which in the case of the sun is 0.0093 radians), and τ is the transmission coefficient of the eye ($\sim$0.5). This equation assumes that the arc of a circle f is equal to its chord, which is a good approximation for small angles such as these.

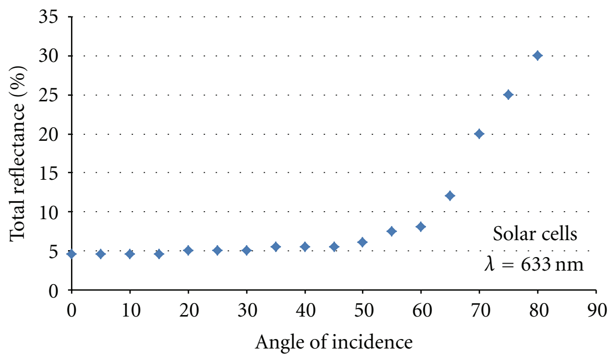


Figure 2: Reflectance as a Function of Incident Angle [8].

3. Ocular Safety Metrics

Next, the calculated values of retinal irradiances were compared to known ocular safety metrics. Extensive research has been done on ocular safety metrics and how to calculate the potential for after-image or retinal burns from radiation in the visible wavelengths. The threshold for retinal irradiance corresponding to the potential for retinal burns has been defined as

$$E_{r,\text{burn}} = \frac{0.118}{\omega} \quad \text{for } \omega < 0.118, \qquad E_{r,\text{burn}} = 1 \quad \text{for } \omega \geq 0.118, \tag{2}$$

where $E_{r,\text{burn}}$ is the retinal burn threshold [W/m^2] and ω is the subtended angle of the sun or 0.0093 radians, Ho et al. [1], and Sliney and Freasier [5]. Ho also compiled data from Metcalf and Horn [2], Severin et al. [4], and Saur and Dobrash [3] to find a fit corresponding to the minimal retinal irradiances that caused after-image (glare). This is calculated by

$$E_{r,\text{flash}} = \frac{3.59 \times 10^{-5}}{\omega^{1.77}}, \tag{3}$$

where $E_{r,\text{flash}}$ is the threshold for potential after image [W/cm^2]. Ho then plotted both of these thresholds and the three regions these thresholds define (potential for retinal burn, potential for after-image, and low potential for after-image) which are illustrated in Figure 3.

The subtended source angle is a function of the size of the image viewed. For the purposes of this report, the image is a reflection of the sun which causes the subtended angle to be constant at 0.0093 radians or roughly 10 mrads.

4. Results

Retinal irradiance was calculated hourly from the years 1998 to 2004 for a fixed-tilt polycrystalline system under the assumptions illustrated in Table 1. These results were then compared to the same results from smooth water.

The assumption of a fixed-tilt system is conservative because, as seen in Figure 2, the reflected component of irradiances increases as incidence angle increases. Having the system held at a fixed tilt increases the average incident angle and therefore the average reflected irradiance.

Table 1: Retinal irradiance assumptions.

Module type	Polycrystalline silicon (p-Si)
Module Tilt/Azimuth	25°/0°
Atmospheric attenuation between the module and the pilot's eye?	No
Subtended angle of the sun	0.00093 radians
Diameter of the pupil in sunlight	0.2 cm
Focal length of the eye	0.0017 cm
Transmission coefficient of the eye	0.5

Table 2: Retinal irradiances.

	Median* [W/cm^2]	Maximum [W/cm^2]
Fixed-tilt p-Si	0.23	0.45
Smooth water	0.13	0.38
Low potential for an after-image <0.10 W/cm^2		
Potential for after-image = 0.10 to 12.7 W/cm^2		
Potential for retinal burn ≥12.7 W/cm^2		

*The median is calculated as the median of all hours with direct insolation greater than 0.

The results of the calculations are displayed in Figure 4 and Table 2. Figure 4 shows retinal irradiances for all hours in the six-year period when direct radiation was present. For example, the blue bar furthest to the left in Figure 4 represents the number of hours in the years 1998 to 2004 where retinal irradiance was between 0 and 0.02 W/cm^2 (approximately 2250 hours). The potential for an after-image corresponding to the different retinal irradiance powers are shown based on the zones defined in Figure 3. The ranges of these zones are quantified in Table 2, showing that a potential for an after-image for both PV panels and smooth water exists but is slight.

Table 2 shows that the median values of both distributions reside in the region "potential for an after-image." The histogram in Figure 4 shows that 79 to 88 percent of hourly retinal irradiances from smooth water and fixed PV modules fall in this region. However, all calculated retinal irradiances fall in the bottom 5% of the region, indicating that although

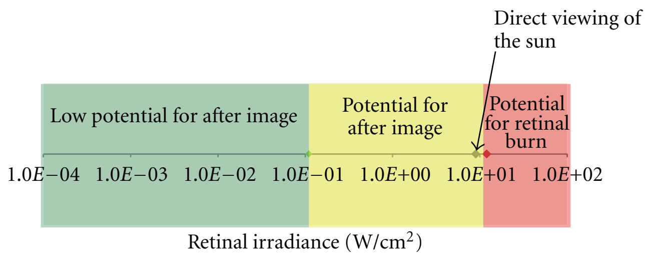


FIGURE 3: Potential impacts of retinal irradiance for a 0.15 s exposure from Ho et al. [1].

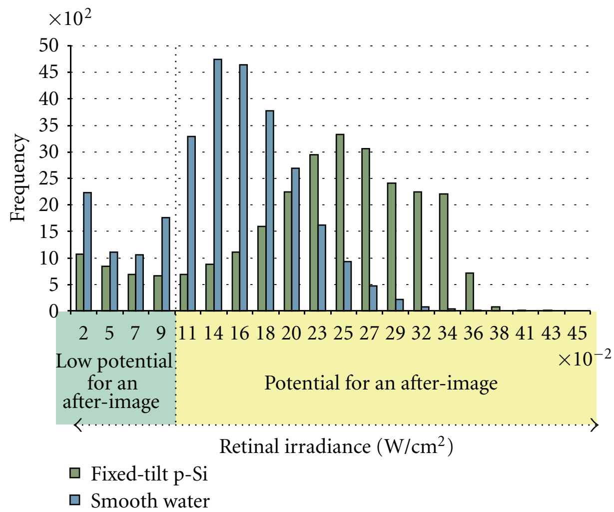


FIGURE 4: Frequency distribution of retinal irradiance 1998 to 2004.

the glare hazard exists, it is relatively low. Figure 5 illustrates this point by expanding the *x*-axis to the entire range of retinal irradiances that would be classified as "potential for an after-image." The major difference between this figure and the one developed by Ho in Figure 3 is the use of a linear, not logarithmic scale.

Figure 6 displays the *maximum* value of hourly glare (highest retinal irradiance) from smooth water and fixed tilt p-Si PV modules plotted onto Figure 3.

As can be seen from Figure 6, the maximum glare from a solar PV array using conservative assumptions is expected to be comparable to that of smooth water. This maximum value is in the region defined as "potential for after-image" where a potential exists, but the potential is on the low end of the range.

The nuisance of glare for pilots cannot be completely avoided. Therefore, it is typically mitigated using darkened visors, sunglasses, and glare shields. If these objects are manufactured to meet American National Standards Institute (ANSI) Standard Z80.3-2001 [10], they will reduce the intensity of retinal irradiance by roughly 70 percent. A 70 percent reduction of retinal irradiances from radiation reflected off of water and PV modules move all retinal irradiance values below 0.14 W/cm^2 as displayed below in Figure 7. Under these conditions, 92 percent of the hours over the six-year period investigated for solar PV would now be in the "low potential" zone in Las Vegas.

5. Conclusions

The potential flash glare a pilot could experience was modeled from a proposed 25-degree fixed-tilt flat-plate polycrystalline PV array installed outside of Las Vegas, Nevada. Hourly insolation data measured onsite via satellite from the years 1998 to 2004 was used to perform this modeling. These results were then compared to the potential glare from smooth water under the same assumptions. The comparison of the results showed that the potential for glare from flat plate PV systems is comparable to that of smooth water and not expected to be a hazard to air navigation.

Glare from ground-based objects can be a nuisance to pilots if proper mitigation procedures are not implemented. Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have reflectivities greater than water and flat plate PV modules as shown by Levinson and Akbari [11], Nakamura etal. [12] and Hutchins et al. [13]. Pilots viewing these objects under specific conditions may experience a distracting level of glare.

The nuisance of glare cannot be completely avoided. Therefore, it is typically mitigated using darkened visors, sunglasses, and glare shields. If these objects are manufactured to meet ANSI Standard Z80.3-2001 [10], they will reduce the intensity of retinal irradiance by roughly 70 percent. A 70-percent reduction of retinal irradiances from radiation reflected off of water and PV modules move all retinal

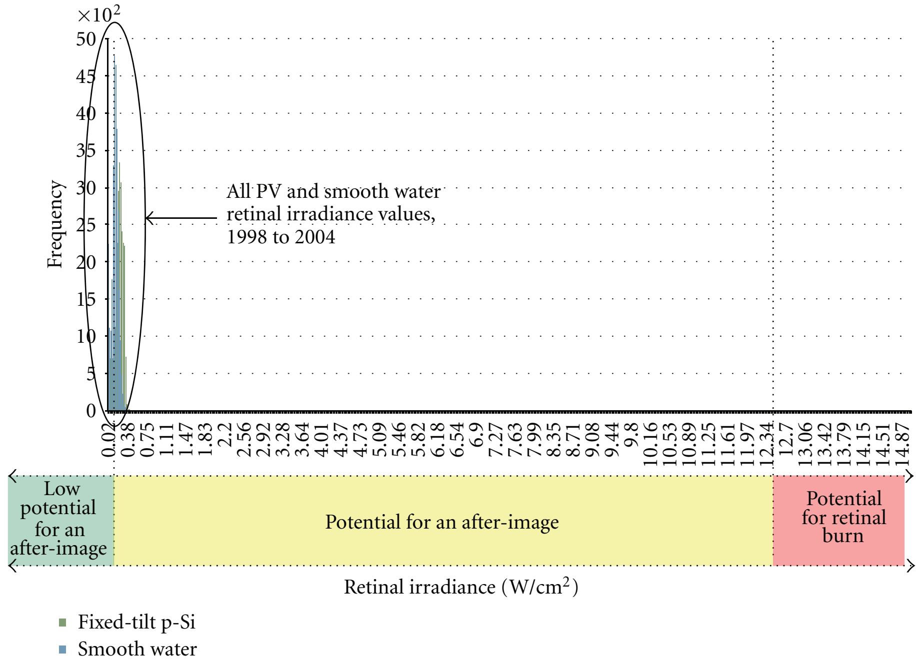


FIGURE 5: Linearly scaled frequency distribution of retinal irradiance.

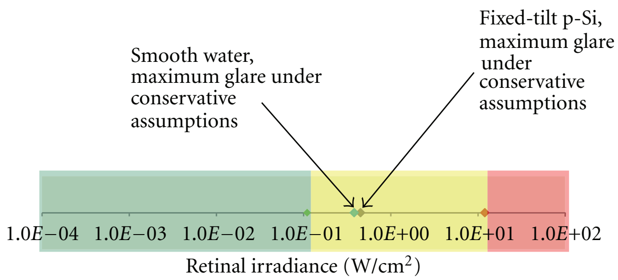


FIGURE 6: Calculated maximum glare at Nellis [1].

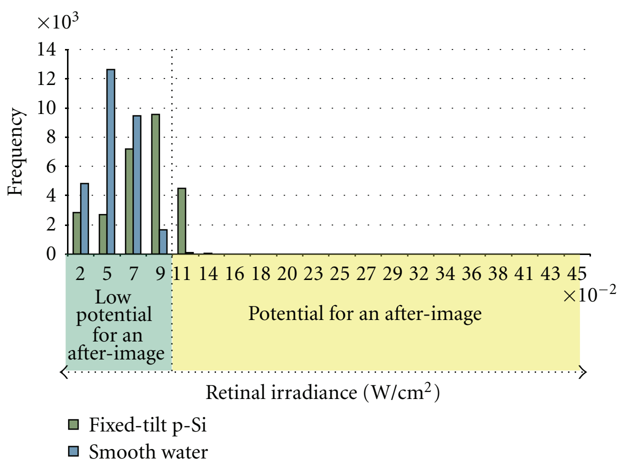


FIGURE 7: Frequency distribution of retinal irradiance with mitigation.

irradiance values below 0.14 W/cm^2. Under these conditions, 92 percent of the hours over the six-year period investigated for solar PV would now be in the “low potential” zone at Las Vegas.

Highlights

(i) Ocular safety metrics were used to quantify the potential for hazardous glare from a photovoltaic system hourly.

(ii) The results show that the glare hazard from smooth water and flat plate photovoltaic systems are similar.

(iii) Glare mitigation is common and significantly reduces glare hazards.

Abbreviations

ANSI: American National Standards Institute
NREL: National Renewable Energy Labs
PV: Photovoltaic
p-Si: Polycrystalline silicon.

Acknowledgments

Special thanks to NV Energy, Inc. specifically David Sims for sponsoring this work, and to Clifford K. Ho, Cheryl M. Ghanbari, and Richard B. Driver for deriving the optical equations applied in this research and for compiling the history of optical safety metrics into a single paper.

References

[1] C. Ho et al., “Methodology to assess potential glint and glare hazards from concentrating solar power plants: analytical models and experimental validation. s.l.,” ES2010-90054, Sandia National Laboratories, 2010.

[2] R. D. Metcalf and R. E. Horn, “Visual recovery times from high intensity flashes of light. s.l.,” Wright Air development Center Technical Report 58232, Air Force Aerospace Medical Research Lab, 1958.

[3] R. L. Saur and S. M. Dobrash, “Duration of after-image disability and viewing simulated sun reflections,” *Applied Optics*, vol. 8, no. 9, pp. 1799–1801, 1969.

[4] S. L. Severin, N. L. Newton, and J. F. Culver, “An experimental approach to flash blindness,” *Aeromedica acta*, vol. 33, pp. 1199–1205, 1962.

[5] D. H. Sliney and B. C. Freasier, “Evaluation of optical radiation hazards,” *Applied Optics*, vol. 12, no. 1, pp. 1–24, 1973.

[6] T. D. Brumleve, “Eye hazard and glint evaluation for the 5-MWt solar thermal test facility,” SAND76-8022, Sandia National Laboratories, Livermore, Calif, USA, 1977.

[7] R. Chiabrando, E. Fabrizio, and G. Garnero, “The territorial and landscape impacts of photovoltaic systems: definition of impacts and assessment of the glare risk,” *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, pp. 2441–2451, 2009.

[8] A. Parretta, A. Sarno, P. Tortora et al., “Angle-dependent reflectance measurements on photovoltaic materials and solar cells,” *Optics Communications*, vol. 172, no. 1, pp. 139–151, 1999.

[9] D. H. Sliney, “An evaluation of the potential hazards of the point focusing solar concentrators at the JPL-Edwards test site,” JPL Consulting Agreement no. JF 714696, California Institute of Technology, Pasadena, Calif, USA, 1980.

[10] ANSI, “Ophthalmics—nonprescription sunglasses and fashion eyewear—requirements,” ANSI Z80.3-2001. s.l., American National Standards Institute, 2001.

[11] R. Levinson and H. Akbari, “Effects and composition and exposure on the solar reflectance of portland cement concrete,” LBL-48334, Lawerence Berkley National Laboratory, Berkley, Calif, USA, 2001.

[12] T. Nakamura, O. Abe, T. Hasegawa, R. Tamura, and T. Ohta, “Spectral reflectance of snow with a known grain-size distribution in successive metamorphism,” *Cold Regions Science and Technology*, vol. 32, no. 1, pp. 13–26, 2001.

[13] M. G. Hutchins, A. J. Topping, C. Anderson et al., “Measurement and prediction of angle-dependent optical properties of coated glass products: results of an inter-laboratory comparison of spectral transmittance and reflectance,” *Thin Solid Films*, vol. 392, no. 2, pp. 269–275, 2001.

Exhibit F

General Design Procedures for Airport Based Solar Photovoltaic Systems

energies

MDPI

Review

General Design Procedures for Airport-Based Solar Photovoltaic Systems

Anurag Anurag [1], Jiemin Zhang [1], Jephias Gwamuri [2,3] and Joshua M. Pearce [1,2,*]

1 Department of Electrical & Computer Engineering, Michigan Technological University, Houghton, MI 49931, USA; fanurag@mtu.edu (A.A.); jieminz@mtu.edu (J.Z.)
2 Department of Materials Science & Engineering, Michigan Technological University, Houghton, MI 49931, USA; jgwamuri@mtu.edu
3 Department of Applied Physics, National University of Science & Technology, P.O. Box AC 939, Ascot, Bulawayo 939, Zimbabwe
* Correspondence: pearce@mtu.edu; Tel.: +1-906-487-1466

Received: 15 June 2017; Accepted: 26 July 2017; Published: 12 August 2017

Abstract: A source of large surface areas for solar photovoltaic (PV) farms that has been largely overlooked in the 13,000 United States of America (U.S.) airports. This paper hopes to enable PV deployments in most airports by providing an approach to overcome the three primary challenges identified by the Federal Aviation Administration (FAA): (1) reflectivity and glare; (2) radar interference; and (3) physical penetration of airspace. First, these challenges and precautions that must be adhered to for safe PV projects deployment at airports are reviewed and summarized. Since one of the core concerns for PV and airport symbiosis is solar panel reflectivity, and because this data is largely estimated, a controlled experiment is conducted to determine worst-case values of front panel surface reflectivity and compare them to theoretical calculations. Then a general approach to implement solar PV systems in an airport is outlined and this approach is applied to a case study airport. The available land was found to be over 570 acres, which would generate more than 39,000% of the actual annual power demand of the existing airport. The results are discussed while considering the scaling potential of airport-based PV systems throughout the U.S.

Keywords: airport; photovoltaic; solar energy; glare; Federal Aviation Administration; economics

1. Introduction

Solar photovoltaic (PV) technology is now well known as a widely accessible, sustainable, and clean source of energy that can be scaled to meet humanity's energy needs [1–3]. After years of steady growth, the PV industry is beginning to meet this potential with approximately 6000 TWh of PV electricity estimated to be generated by 2050, which is roughly 16% of the total global electricity demand [4]. This much solar PV-generated electricity will necessitate substantial surface areas dedicated to PV deployment because of the diffuse nature of solar energy. Much of this need can be met via rooftop PV or the relatively immature building-integrated PV (BIPV) market [5–10]. The remainder will need to be met by large-area solar PV farms on either land-based solar PV farms [11–14] or even water-based floating solar PV farms [15–22]. However, as the global population increases 1.15% per year [23], attractive land and even waterways will become more valuable, especially in densely populated areas. This has the adverse consequence of creating competition for limited land resources between food and energy demand [24–26], which will exacerbate the current problem of 870 million people who are chronically malnourished [27]. This means practically that all available non-food producing surface areas should be used before energy production impacts food production.

One source of large surface areas that has been largely overlooked for PV deployments and is not suitable for food production is the surface areas surrounding airports [28]. Airports have large electric load demand, and are generally located near population centers with even higher demands, and also have large unused land areas due to existing design protocols. By 2013, the total number of airports in United States of America (U.S.) was over 13,000 (paved and unpaved) [29], out of which the Federal Aviation Administration (FAA) currently includes over 4500 as public, general aviation use airports [30], which makes airports even more of a potential market for solar PV systems.

One of the factors that influences economic viability of large solar farms are the investments pertaining to acquiring and maintaining suitable land. Thus, airport property has the potential to substantially decrease the land cost as the property under airport authorities has no value for any other use. Another advantage comes in terms of maintenance, as the land under consideration is maintained by the airport authorities from any physical obstruction above ground, thus making it an ideal location for solar PV. There are 30 airports in U.S. [31] and many more across the globe that already have solar power partially supporting their load demands, including Kempegowda International Airport and Cochin International Airport in India [32], and Indianapolis International Airport [33], Tucson International Airport [34], Chattanooga Airport [35], San Francisco International Airport [36] and Denver International Airport in the U.S. [37]. However, the economically viable application of PV [38] in airports is far from saturated, as there are lingering safety concerns from reflectivity and radar interference among airport operators for installation of large-scale PV systems within their land areas [39]. In addition, there is no generalized approach to apply solar PV systems to airports.

This paper rectifies these impediments to further PV deployments at airports by reviewing existing work on PV and airports and providing a new generalized approach to overcome the three primary challenges identified by the F.A.A. [39]: (1) reflectivity and glare; (2) radar interference; and (3) physical penetration of airspace. First, these challenges and precautions that must be adhered to for safe PV projects deployment at airports are reviewed and described. Since one of the core concerns for PV and airport symbiosis is solar panel reflectivity, and because this data is largely unavailable, a controlled experiment is conducted here to determine worst-case values of front panel surface reflectivity. Then a general approach to implement solar PV systems in an airport is outlined and this approach is applied to a case study airport: Houghton County Memorial Airport (CMX) in Hancock, Michigan. The results are provided and discussed while considering the scaling potential of airport-based PV systems.

2. Background on Three Primary Road Blocks to Photovoltaic Systems at Airports

The paper reviews methods to overcome the three primary roadblocks identified by the F.A.A. to deployment of solar PV systems at airports [39]: (1) reflectivity and glare; (2) radar interference; and (3) physical penetration of airspace.

2.1. Reflectivity and Glare

Reflectivity in this context denotes the ability of the PV module surface to reflect light, which may interfere as glare with pilot or airport staff visibility. The possible impacts of PV module reflectivity may lead to either glint or glare, or both. This can cause a brief loss of vision (also called flash blindness), which is a safety concern for the pilots. Flash blindness for a period of 4–12 s (i.e., time to recovery of vision) occurs when 7–11 W/m^2 (or 650–1100 $lumens/m^2$) reaches the eye [39]. It is recommended when designing any solar installation for an airport to carefully consider the final approach of pilots and guarantee that no placed installation section will give any face glare that is straight ahead of them or within 25° of straight ahead during final approach [40]. Often the maximum solar irradiation of 1000 W/m^2 is used in calculations as an estimate of the solar energy interacting with a module when no other information is available [39]. However, this may be a poor assumption as PV modules have been optically engineered to minimize optical reflection in both conventional [41,42] and thin film PV devices [43,44]. Most PV are using anti-reflection coating (ARC) [45,46] and future PV are expected to integrate metamaterial perfect absorbers into solar modules [47,48], which would be expected to reduce reflection even further [49,50]. The exact percentage of light that is reflected from PV panels is currently best estimated using the Solar Glare Hazard Analysis Tool (SGHAT) [51].

This was a free online tool developed with U.S. tax dollars by the Sandia National Lab in the U.S. Unfortunately, it was disabled in 2016 and is currently available for licensing from Sandia only to commercial ventures. The impact of denying access to publicly funded research in this area will be discussed below. In addition, the reflectivity is not absolutely known for all PV modules. However, the vast majority of PV modules on the market contain some form of anti-reflection coating, and this loss (due to reflection) is generally considered to be only a few percent [52]. In addition, outside of very unusual circumstances, flash blindness can only occur from specular reflections.

A study and report published by Federal Aviation Administration in 2015 [40] gives further insight on how glare actually affects aircraft aviation and compares PV glare to other common sources of glare. On performing a thorough study with pilots, it was found that majority of pilots had encountered glare with durations between 1 and 10 s with longer durations being encountered for objects other than direct sunlight or solar panels. This study concluded that for most pilots, glare emanated primarily from bodies of water. One of the solutions to the glare problem is avoid angles of glare between approaching planes and solar PV modules using SGHAT as a guide and the other potential solution is to eventually achieve lower reflectivity from PV surfaces compared to typical source of glare from other real-world objects like water, buildings/glass windows, other aircraft and even snow. It should be noted that the real location considered in this paper has snow in 5 of the 12 months of the year and hence it will be safe to assume that glare off snow here will be one of the highest compared to other locations. To counter this problem, which is primarily that of an unknown, a reliable method to calculate the percentage of specular reflection off a particular PV module shall be measured and compared to a theoretical model. Experimentally determined reflection values will be addressed below.

2.2. Radar Interference

PV systems could cause negative impacts on radar, NAVAIDS (navigation aids) and infrared instruments called communication, navigation, and surveillance (CNS) by causing interference [39]. Interference of radar and NAVAIDS (despite passive components) occurs when objects are placed too close to a radar sail or antenna and obstruct the transmission of signals between the radar antenna and the receiver, which can be a plane or a remote monitoring location. Metal components on the PV racking may also cause reflected signals. However, due to PV systems having a low profile these risks are low. For example, most large-scale solar farms are of low height profiles like the Topaz Solar PV Farm in California, which is approximately 1.7 m (5.5 ft.) above ground at its top edge, minimize visual impact [53]. If solar PV systems do not represent any level of risk of interfering with surrounding CNS facilities, solar PV project sponsors do not need to conduct studies on their own to determine impacts on CNS facilities when siting a solar energy system at an airport [54]. Due to their low profiles, solar PV systems typically represent little risk of interfering with radar transmissions. In addition, solar modules do not emit electromagnetic waves over distances that could interfere with radar signal transmissions, and any electrical facilities that do carry concentrated current are buried beneath the ground and away from any signal transmission [39]. The one area of potential problem of interference might occur due to the use of metal parts for the racking of the modules. This has not been found it practice, but there are also already alternative materials that can be used for PV racking including plastic tension-based systems [55,56], fiber glass [57], plastic [58] and concrete [59]. These alternative material systems may be considered for airports with metal racking concerns. Lastly, solar energy not converted into electricity by the PV device is converted into heat, raising the temperature of the PV modules in operation normally to about 50 °C in full sun. Thus, impacts on infrared communications can also occur because the solar PV continue to retain heat into the first part of dusk, and the heat they release can be picked up by infrared communications in aircraft [39]. Although this risk is also low, a certain safe radial distance of 150 ft. must be maintained between communication instruments, the control tower and PV modules to avoid all mechanism of interference. It should be noted that some past solar fields have required greater setbacks up to 500 ft. [39].

2.3. Physical Penetration of Airspace and Land

No physical structure is allowed to intervene in spaces that may lead to any safety issues at airports. Hence airspace inside and around any airport is pre-defined where no physical body of any kind is allowed to stand, as shown in Figure 1 [60]. The important volumes in Figure 1 from a PV system installation perspective are in the lower right. The primary surface is a surface longitudinally centered on a runway shown in blue. Next, a horizontal plane 150 ft. above the established airport elevation is shown in dark grey. The approach surface of the aircraft area in blue and transition surface in purple along with other aerial zones concerned with flying aircraft only. All these zones are aerial (150 ft. and above the runway) and will not represent an interference hazard with any of the typical surface solar PV racking designs [61]. The only point of concern will be the restricted zones defined on the actual surface around the runway. This will be discussed in detail in Section 4.3.

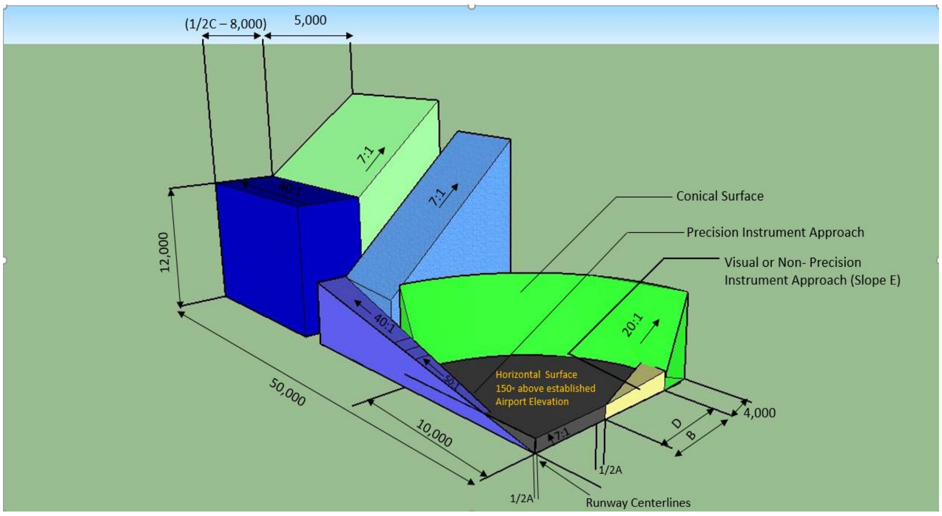


Figure 1. Defining aerial zones defined for airports, which are adapted from [60]. The lower right is the region of relevance for photovoltaics (PV) systems. The primary surface is a surface longitudinally centered on a runway shown in blue, a horizontal plane 150 ft. above the established airport elevation is shown in dark grey, and the conical surface is shown in green.

3. Experimental Determination of Reflection from a Photovoltaic Module Surface

As noted in Section 2.1, despite glare being considered one of the biggest challenges for an airport solar PV system deployment, there is little available worst-case data on how much of the incident light is due to specular reflection from a standard solar module. Experiments are conducted here to provide background data on the effect of PV array tilt angle on the amount of glared produced from the face of a module in non-glancing angle approaches. The results are also used to validate/correlate part of the data provided by the FAA for PV systems located near airports.

Experimental data was obtained using the following protocol. A small area solar simulator (PV Measurements model SASS, class-BBA) was used as a light source. A calibrated photovoltaic reference cell was used to calibrate the solar simulator to 1 sun (1000 W/m^2) using an AM 1.5 spectrum prior to performing the reflection measurements. A 255 W Sharp (model make Sharp #ND-255QCSBX) crystalline silicon-based solar module was used as a reflecting surface (solar PV panel surface). This type of module was chosen as the majority of PV modules on the market are silicon crystalline or polycrystalline silicon absorber material, and this module has standard optics (e.g., anti-reflective coating on Si but not on glass). This module is typical for large commercial applications, with maximum power (P_{max}) 250 W (under standard conditions), tolerance of P_{max} of +5%/−0%, and the temperature coefficient is −0.485%/°C. A mounted photodiode was used to measure irradiance from both the incident and reflected beam (glare) as a direct function of current generated. The photodiode sensors deliver a current that depends on the optical power and wavelength of the incident beam. Here it is used to measure the reflected glare noted in percentage of the incident irradiation on the panel. The tilt angle was measured using an inclinometer (±0.5°). The distances between the light source, detector and the panel surface, as well as the relative positions, were kept constant throughout the entire experiment. First, measurements were made to determine the irradiance on the panel surface for normal incidence angle (90°) and zero reflection. Then subsequent measurements were made to determine the reflected irradiance for a range of panel tilt angles from 10° to 70° (limited by setup geometries) in 10° incremental steps. Three measurements at the peak location of reflectivity were obtained and averaged for each tilt angle in order to improve the accuracy of the measured results and minimize random error.

4. General Approach to Design Solar System for Airports

4.1. Airport Type and Surface Selection

There are several variables to consider when applying a solar PV system to an airport. First, the location of airport. If the airport is located in the city, like Ronald Reagan Washington National Airport (DCA), it does not have much land available per unit size as compared to more rural airports. These cases where there is limited ground area available should first consider the installation of solar PV on rooftops of buildings and then look at any potential ground area for ground-based systems. On the other hand, if the airport is located in a rural or remote location, like Washington Dulles International Airport (IAD) or CMX in Hancock, Michigan, there is a relatively larger land area available per unit load within the airport. This situation favors a large uniform designed ground-mounted system with roof-mounted or BIPV playing a relatively minor role.

Second, the annual weather conditions for the airport is also a factor for airport PV system design. Although the location of airport is already selected for better weather conditions for airplane landing and taking off, weather still plays a major role in PV system performance. For example, the rural CMX has the largest number of delayed and canceled flights in the U.S. due primarily to weather conditions [62]. In addition, the region it is located in is the upper peninsula of Michigan, which records some of the largest snow events in the U.S. [63], and snow has an impact for annual PV output [64–68]. Thus, in such cases the adverse (snow losses [63–68]) and positive effects of weather (i.e., surface albedo [69]) effects need to be taken into consideration in simulation and designs.

Third, the energy consumption of the airport is a factor for sizing an airport-based solar PV system if solar energy is not to be exported to the grid. Based on how busy and how large the airport is the energy consumption varies for different cases and can be substantial. For example, San Francisco International Airport (SFO) reported 322,927 MWh of electricity used by itself and its tenants in Fiscal Year 2010 [36]. This is enough electricity to meet the annual electricity needs of over 48,000 California residents [36]. When considering airport PV systems the variability of the airport load itself should be modeled carefully as the variability can be substantial. For example, in a 2015 report on the Los Angeles International Airport (LAX) electric consumption was 184,416 MWh (14.51% more that its consumption in 2010), which was actually an increase in electricity consumption by approximately 32% until 2014. It was only because of the change in their policies and power management that power demand was reduced in the following year [70].

If the land area for solar PV is large enough and the airport size is relatively small, there is possibility of achieving a grid neutral airport. If more land area is available for PV solar system, then the generation capacity is enough to even feed back into the grid. However, if the land area around a busy airport is small, only partial energy demands will may be fulfilled by solar PV system.

4.2. Solar Photovoltaic System Design Parameters

There are several PV systems designing/modelling software including: proprietary (e.g., PVSyst, SolarGIS, INSEL, Solar Design Tool, etc.); free government supported methods (e.g., NREL's

System Advisor Model (SAM) [71], Solar Prospector [72], PVWatts Calculator [73] and Canada's RETScreen [74]); and open-source methods (e.g., r.sun/GRASS [75–77]) available for predicting; weather, solar flux and basic PV systems performance and modeling. This paper uses SAM for the performance and financial model designed to facilitate decision-making for the project considered. Using SAM performance predictions and cost of energy estimates can be made for grid-connected/independent power projects based on installation and operating costs and system design parameters that are specified as inputs to the model. The solar resource will affect the design along with the type of balance of systems (BOS) and racking configuration. As all airports constitute long and mandatory boundaries, non-traditional PV system designs may be the best option for the most restricted surface areas. For example, with large spacing between boundaries and airport properties (i.e., towers, roads, etc.), bi-facial solar PV could be another way to increase the overall solar power profile of any airport system. Though low on efficiency compared to conventional PV systems, bifacial PV can provide power and cost benefits by being a protection boundary as well as noise barrier to some extend apart from providing power alone [78]. Based on the sun location during different hours of the day and seasons of the year, the tilt angles of the solar modules will be determined normally to provide the largest annual output [79,80]. The optimized angle for solar modules will also need to take into account weather (e.g., snow conditions [63]).

4.3. Available Surface Area for Photovoltaic System

Based on airspace restrictions detailed in Figure 1, the FAA restricts the use of the surface areas in airports. This is detailed in Figure 2. The runway (grey), runway object free area (blue), runway protection zone (RPZ) (light green) and controlled activity (yellow) areas all prohibit PV deployment. Figure 2 shows the areas available for PV deployment in green.

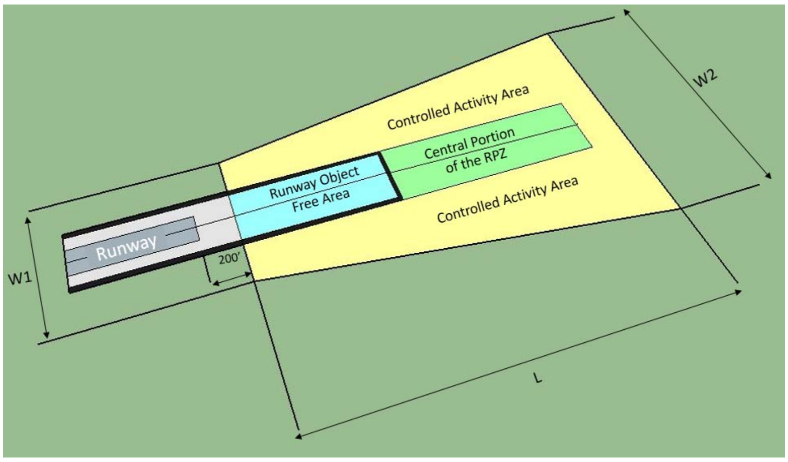


Figure 2. Surface areas with and near the end of a runway [39], which cannot be used for PV deployment. Only surface areas coated in green can be used for PV.

Using the map of the airport, the land area that is not in conflict with the restricted area and other land reserved for any other purposes should be identified as the area in which solar PV systems can possibly be deployed. For this, tools like ArcGIS can be used. By using the Area Solar Radiation Tool in the ArcGIS Spatial Analyst extension, a solar map can be generated from the georeferenced image specifying target locations, latitude and a yearly solar interval. This solar map takes into consideration the changes in the elevation (azimuth) and position of the sun, as well as any possible shading effect caused by buildings or other objects in the input raster. Such GIS software also derives raster representations of a hemispherical view shed, sun map, and sky map, which are used in the calculation of direct, diffuse, and global solar radiation [81]. A similar approach can be used for free with r.sun and GRASS [76,77,82]. Because of the direction of runways, the planes land and take off in both direction the runways. Thus, the different locations of solar PV system panels can have different glare effects on a plane navigating around the airport. After determining the orientation and angle for a solar PV system for an airport, it is advisable to set the solar modules in the land area which is facing off the runways. Details of the approach will be presented in Section 5 for the case study airport.

In addition, land proposed for PV deployment at airports should not only be available for power production now, but also be free from any future expansion plans (e.g., proposed future runway extensions or new buildings). However, it should be noted that even if a certain section of land is proposed for use after 20 years, a PV system can be proposed for this land on lease for some time to not only make the project economically profitable, but also as a better use of the land for the time being (it is expected that solar PV technology will continue to improve [61] fast enough to compensate for the generation loss by increasing efficiency in permanent PV systems).

4.4. Airport Baseload Power to Photovoltaic Generation Potential Comparison

After determining the available land for a solar PV system, energy production potential by the solar PV system can be calculated for any time of the year. The resultant solar energy produced in calculations can be compared to the actual electric demand based on historical data and projections of the airport from an annual to daily basis, which will further help determine if the airport can be fully supported by solar power or not, and in case of excess power being generated, how much can be fed back to the grid for net metered systems.

During winter periods, energy production potential must to take into account snow losses that can be evaluated using experimental data from Heidari et al. [63] study, which used the same site as this study to perform actual snow loss calculations for solar PV systems at various tilt angles. The power for each snow-exposed module placed at airport site was determined using Equation (1), while Equation (2) was used to evaluate the power from modules without snow cover.

$$P_m = \frac{I_t(T)(P_{STC}(1 + C(T - T_{STC})))}{I_t - I_{STC}(1 + \alpha(T - T_{STC}))} \quad (1)$$

$$P_C = (G_t(1 + \beta(T_{STC} - T))) \times \frac{P_{STC}(1 + C(T - T_{STC})}{1000} \quad (2)$$

where:

α	Temperature coefficient of current, module (1/°C)
β	Temperature coefficient, pyranometer (1/°C)
C	Temperature coefficient of power, module (1/°C)
E_{loss}	Energy loss (kWh)
I_t	Short-circuit current measured at time t (A)
I_{STC}	Short-circuit current at Standard Test Conditions (STCs), (A)
$P_{C,\,t}$	Power that can be extracted from each virtual clean module (without snow) at time t (Watts)
$P_{m,\,t}$	Calculated output power of snow-exposed module (at various angles and heights) at time t (W)
G_t	Global irradiance obtained by pyranometer (at various angles) at time t (W/m^{-2})

Thus, the snow loss due to snow was calculated as the difference in energy without snow P_C versus the energy obtained from snow-covered modules P_m [63] using Equation (3).

$$E_{loss}(t) = (P_C \times t) - (P_m \times t) \quad (3)$$

5. Case Study

To clarify the methodology a case study is provided using the Houghton County Memorial Airport (CMX) in Hancock, in Michigan's Upper Peninsula (UP). The UP is situated between Lake Superior (along its northern border) and Wisconsin, Lake Michigan, and Lake Huron to the south.

It provides an extreme rural case as the UP encompasses 29% of Michigan's land area, but has only ~3% of the total population [83]. The region experiences long, cold and dark winters with some of the heaviest snowfalls in the United States, which make annual off-grid PV system design particularly challenging [84]. However, short, relatively cool summers with average-high August temperatures of only 22 °C reduce the negative temperature effects on PV performance [85]. In addition, because of the northern latitude of the UP, daylight hours are short during winter and long in the summer, which heavily skews PV production towards summer. At the same time the business case for PV systems in this region is relatively easy to make as the levelized cost of electricity (LCOE) [38] is far less than the effective rates for a consumer per kilowatt hour (kWh) which is comparable across all utilities by incorporating energy changes, service charges, state-mandated charges, and power supply cost recovery factors, which ranges up to over $0.24/kWh (more than double the U.S. average) [86].

5.1. Airport Land Zones and Photovoltaic System Sites Identification

CMX airport was chosen due to access to real time testing and data collection for the validation of the proposed methodology [87]. Furthermore, CMX is currently planning to expand its infrastructure in the near future and considering integrating PV solar power, in addition to other methods of becoming a more environmental friendly and economically viable airport by cutting purchased electricity, which is the highest in the region. Due to the availability of large vacant lands (over 200 acres, as seen in Figure 3, and the low electricity demand, it is possible to design a PV system for better than net zero and thus substantial excess generated solar electricity could be exported to the grid. Figure 3 shows the outer physical boundary (in green) with clear zones (in blue) and the runway protection zones at the ends of the runways (in pink).

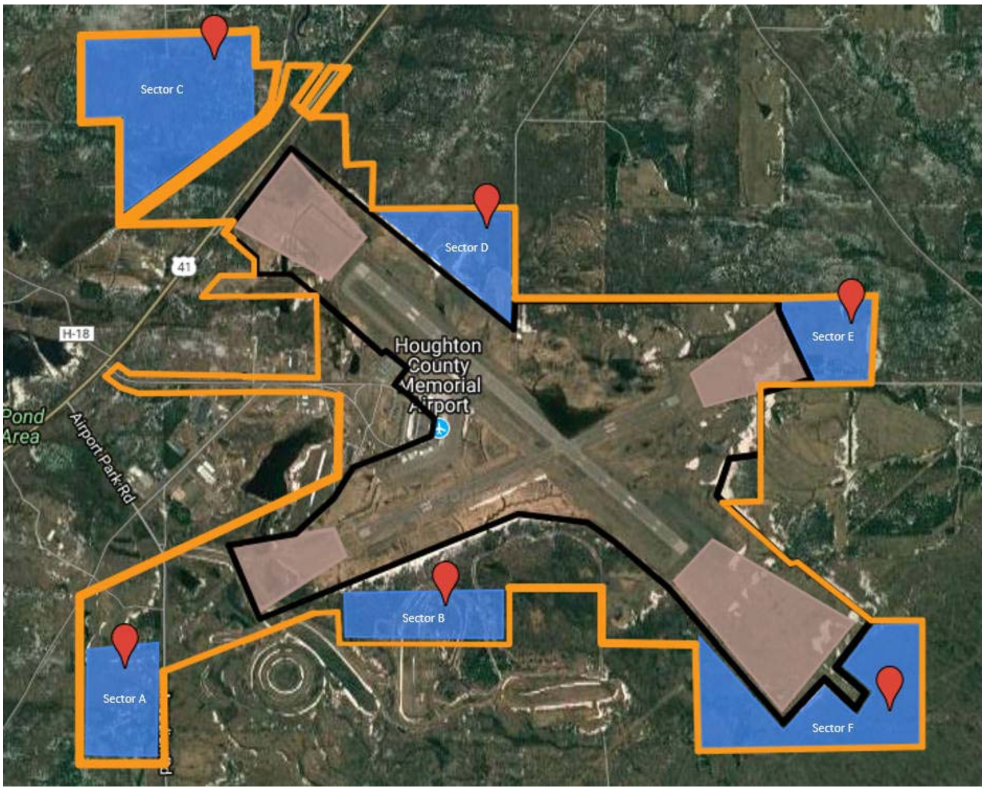


Figure 3. Ariel view of Houghton County Memorial Airport (CMX) airport, with the PV deployment zones marked. Note: The four pink trapezoid zones are the restricted areas showed in Figure 1; black lines enclosed clean area, and no objects other than necessary terminal buildings are allowed in this zone; the orange line enclosed the area which is total airport land property, and; the six red pins are suggested land/sites for the deployment of solar PV systems.

The spatial data to consider includes different building location details, boundaries of different sections across the airport, data regarding any object free zone, runways, marking of future buildings and extension work for existing runways, and boundary fencing details.

5.2. Photovoltaic System Modeling/Simulation

For simulating the PV system for the airport, System Advisor Model [71], developed by the National Renewable Energy Laboratory (NREL) is used. First, in the "Location and Resource" section of the model, actual data for CMX airport in Hancock for 2016 was used in the simulation. In the "resource data" section, SunPower SPR-445J-WHT-D (power at standard testing conditions (STC) is 445W) solar modules were selected. Suitable configurations for the sub-arrays were then made. Since the location of CMX airport is in the northern hemisphere, the azimuth is selected to be 180° so that the system faces south. Using freely available and industry accepted software (SAM), the solar flux available in Houghton County, Michigan (located in the west-central part of the UP) and class 2 TMY3 (typical meteorological year) solar data averaged from 1991 to 2005 [88], the optimal design was found to be a 30° tilt with south facing arrays receiving global horizontal of 3.41 kWh/m^2/day. Although based on [66,67], 60 degrees is optimized for minimizing snow-related losses, as it makes it easier for snow to slide off the modules, the tilt angle was set as 45. After calculation, for 80 acres of land, without snow losses the unobstructed system on SAM produces 2.33% more power for 30° tilt compared to 45°. However, after taking snow losses for both angles into consideration [66,67], power produced at 45° tile is 2.8% more than power from 30°. Thus 45° tile angle was chosen. For this study, first 80 acres (case 1) of land is evaluated out of the approximately 570.4 acres (case 2), all the blue sections in Figure 3, that is, Section A to F, of potential land available for solar PV system. For both case studies a packing factor (ratio of module area to unused area) of 0.4286 was used. The sub-PV array configuration for case 1 is shown in Table 1 below. Thus, for case 2 the solar PV farm was 2,308,000 m^2 and the total module area was 692,530 m^2.

Table 1. The sub-PV array configuration for case 1. Note: Azimuth indicates the horizontal direction of the solar array and tilt is the tilt angle of the modules with respect to the ground.

String No.	Configuration	Description	Unit of Measurement	Details
1	String Configuration	Strings in Array	No.	5619
2	Tracking & Orientation	System	-	Fixed
3	-	Tilt	Degree	45
4	-	Azimuth Angle	Degree	180
5	-	Ground Coverage Ration		0.3
6	Estimate of Land Area and Usage	Total Module Area	Meter square	97,186
7	-	Total Land Area	Acres	80

The loss settings are as follows: module mismatch is 1%; diodes and connections is 0.5%; DC (direct current) wiring is 1%; nameplate is 1%; and AC (alternating current) wiring is 1%. For the study, actual load data with each unit cost for each energy meter at the airport was acquired and the total demand and total bill payment of each month in 2015 were collected, and are shown in Table 2 [89]. In winter (November to February), the demands are high due to the heating systems loads compared to no such demand for May and June. The demand in July is slightly higher compared to June and August since there is one additional electricity demand from recreational vehicles (RVs), which consumes a little more electricity compared to other months.

Table 2. Total demand and total bill payment of each month in 2015.

Months	Total Demand (kWh)	Total Bill Payment (US$)
January	48,507.00	8612.93
February	45,590.00	8513.88
March	42,509.00	8049.09
April	35,852.00	7149.05
May	31,336.00	6568.81
June	26,641.00	5853.03
July	33,420.00	6663.00
August	29,280.00	6138.03
September	26,817.00	5871.14
October	29,894.00	6167.57
November	32,837.00	6783.91
December	39,391.00	7549.51
Total Annual Demand	422,074.00	-
Total Amount Paid	-	83,919.95

6. Results and Discussion

The reflection off a solar PV panel from most near normal angles is less than 3% and represents no risk to air traffic, as can be seen in Figure 4. Figure 4 shows the percentage of reflected light as a fraction of the total incident radiation from the surface of a PV module as a function of the incident angle, θ. This percent of reflected light is measured at the location of peak intensity as a function of the current generated by a photodiode. The results show that the reflection from solar module surface with incident radiation of 1 sun from angles of 10 to 70° varied from the range of 2.08% to 7.15% of the incident radiation. Overall, the reflections off of the PV panel surface were found to be pretty stable until the tilt reached glancing angles, from where it started to increase substantially. This is akin to the behavior of light reflecting from a still source of water such as a pond. The refractive index of still water is 1.33 [90] and the front glass of solar PV modules are made of standard soda lime glass, which has a refractive index of 1.50–1.52. It would thus be expected that for a given angle reflection from a PV front glass surface without any antireflecting (AR) coating is less intense than that of water. Now, with the current progress in solar module technology and development in anti-reflection materials such as materials with an index of refraction of 1.05 [91,92], it is safe to assume that solar PV module will have reflection off their surface dropped further with future technologies [93–96]. However, even today with the refractive index off PV with AR coating dropping below 1.33 to 1.20–1.30 [97], PV poses no (or presents tolerable/safe) hazards from reflection for airport solar PV projects. By comparing the results of the experiments described here (Figure 1) with estimates from [97], it is clear that modern PV have less intense reflectivity than still surface water. Although PV are mounted at a tilt angle with regards to the surface, the risk of flash blindness is only present for the higher angles (e.g., glancing angles). It should be noted, however, that typical AR coatings are generally optimized for overall reflectance loss, which does not necessarily minimize glancing angle reflectivity or specific polarizations. By changing the cover glass of solar PV, these glare properties can be optimized for airports. For example, glass with strong structured surfaces have proven to be most favorable as its diffusing effect is more effective than antireflective coatings, and initial tests on PV modules showed no performance loss will be induced if strong structured glass is used as a cover [98]. Minimizing this already small risk can be accomplished by selective placement and orientation for plane traffic approaches.

In addition, the use of low-tilt angle arrays would also reduce this risk. The disadvantage of such low-tilt angle arrays is the reduced energy yield per installed unit power of the PV system. However, as the cost of PV modules themselves have dropped a low-tilt angle system enables closer packing of modules (e.g., higher power per unit area) and can increase the solar electricity generated per unit area at an airport. In addition, for airports with surface water, floating solar PV farms [15–21] and even aquavoltaics [22] would enable an increased area for PV, as well as possibly reducing water surface glare.

The most straightforward method to eliminate glare problems is with the selective placement and orientation of PV for the plane traffic approaches is best accomplished with SGHAT [99], using data from this paper and recent bidirectional reflectance distribution function work on different materials on solar installation glare [98], and following careful siting strategies [100–102]. As noted earlier, this best approach was free as the software was funded by the U.S. government and then, for reasons not known to the current licensing executives at Sandia National Laboratories, the software became available only for commercial licensing; currently the use of the software is only available from one vendor, Forge Solar, with subscription plans running from a free trialup to US$156/month [103]. If it is assumed that each airport in the U.S. would want access to the Enterprise version to enable the full optimization of PV arrays, as well as enhanced flight paths over a year of planning, the cost would be US$156/month × 12 months × 13,000 airports the cost would be over US$24.3 million. This cost could in part explain why such a small percentage of airports in the U.S. have moved to PV despite the overwhelming economic advantages seen by large-scale PV systems. This thus illustrates the need for government-funded research to ascribe to open source principles in both software [104,105], research [106] and hardware [107,108] so that the value created from publicly funded research is not locked behind paywalls, which both limits access, but also (as in this case) the deployment of superior technologies.

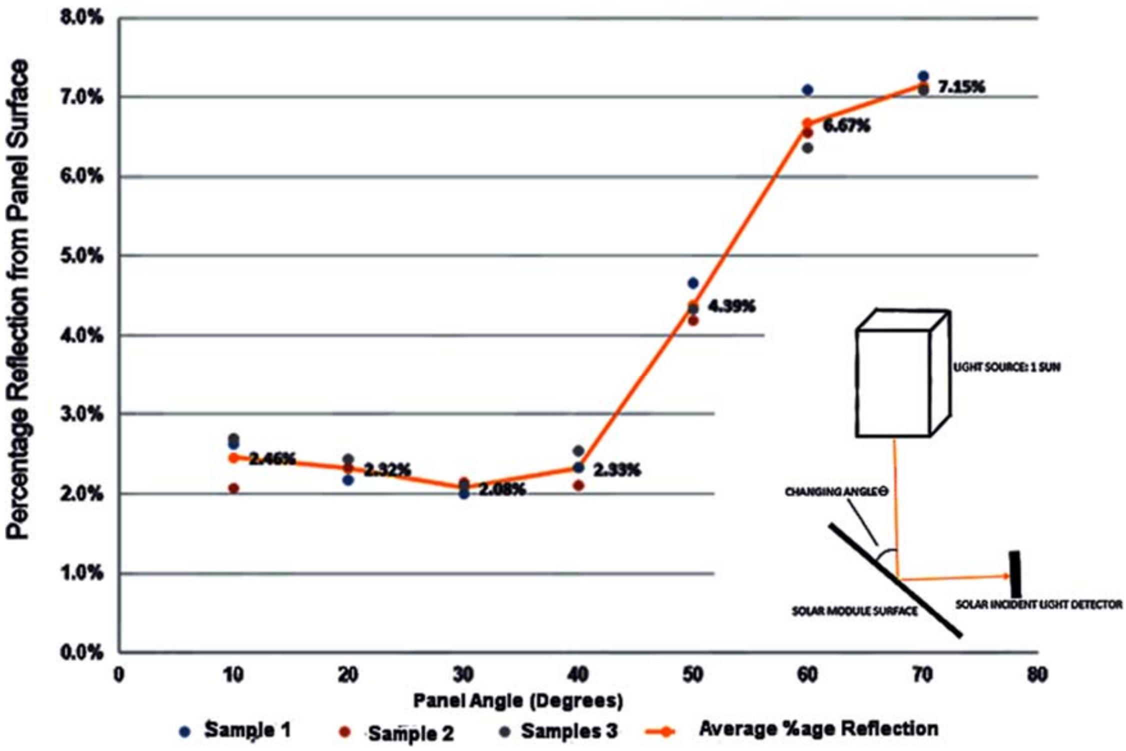


Figure 4. Percentage of reflection light from the surface of a PV module as a functional angle at the location of peak intensity. Inset: experimental setup for measurements.

Further, it is found that potential solar PV projects of substantial size do not possess a risk to aviation from an airspace penetration point of view. Under no conditions would a typical solar PV farm penetrate the approach surface for flights based on the height of PV racks (and low tilt angle racks are even shorter). To further secure the areas near to runways and control tower buildings, proper clearance can be taken from airport authorities themselves, which should result no compromise on the potential land for solar PV farm usage, as seen in Figure 3.

The CMX airport has more than 570 acres of land (all the blue sections in Figure 3, i.e., Section A to F) available and it must be kept clear of trees and vegetation by the airport authorities. Therefore, there is great potential for solar PV system since, in addition to producing solar electricity, solar PV deployment could reduce direct labor costs or shift them to a solar energy provider (e.g., if a standard power purchase agreement (PPA) is used). In the case of CMX, to be extremely conservative case 1 simulation results are first based on using only 80 acres of available land. Some of the available areas from Figure 3 are sized as zones sized for perspective. This case 1 system would have a much smaller capital investment than a full potential system of 570 acres (case 2). In addition, not only would it ensure that under no circumstances would the system interfere with the airport's existing functionality (the same as the 570 acres), but it would also enable all future expansion plans. To underscore how conservative (low estimation of available PV area) this case 2 estimate is, consider that there are existing cases where approval was given to place part of a PV farm in runway protection zones, which were excluded from the estimates here [39].

The three rectangles (sections A,B,C) highlighted on the left in Figure 3 are better for deploying solar panels compared to other three core potential array locations. The reason is the three-land area are either on the south part of airport (which have least effect glare on airplane) or far away from runways (which has least effect when plane is landing or taking off). In the case 1 simulation, 80 acres of land for deploying solar panels is assumed. In Figure 3, Section A and B is chosen for deploying solar panels.

After simulation in SAM, the monthly energy production is as shown in Figure 5. The data is the energy production before accounting for the snow losses. The next step is the need to measure the snow loss, which could be calculated using Equations (1)–(3) [63].

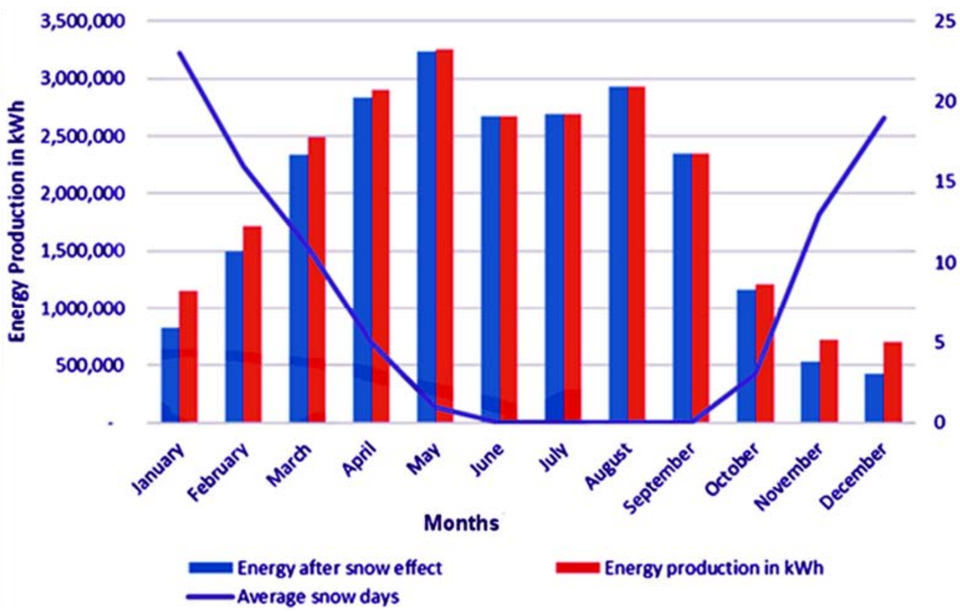
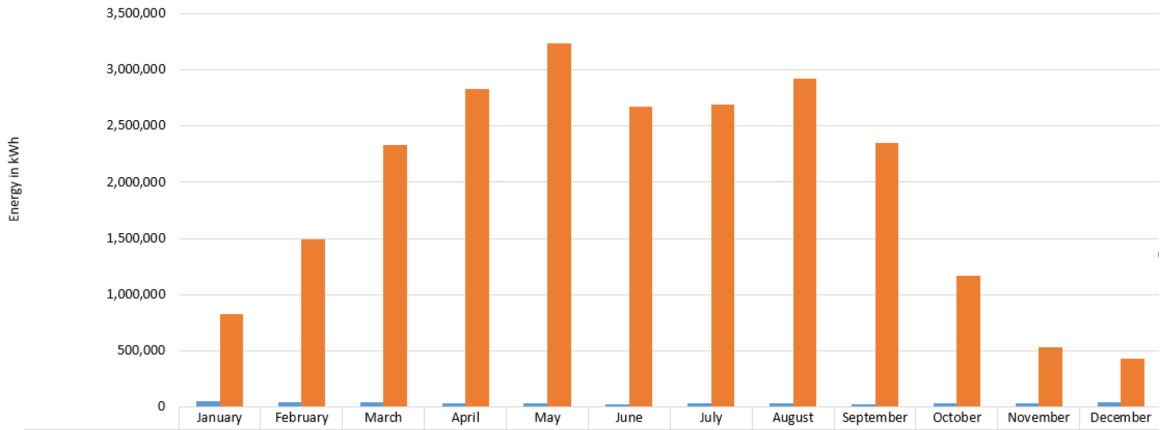


Figure 5. Monthly energy production with production with snow losses based on the configuration of solar system.

Results based on Equation (1)–(3), along with simulations studies, showed that with the increasing tilt angles from 0° to 45° for the unobstructed panels, energy loss decreased from 34% to just 5% annually. With the obstructed modules, the losses varied in the range of 29–34% of the total energy produced annually [63]. It was not surprising to find the losses for obstructed and unobstructed panels to be similar as both have the same snow covering in winters due to low or no tilt in the panels. The difference is substantial at higher tilt angles. The results showed that the optimum tilt angle for the system without snow is 30 degrees, producing 25.4 million kWh, but this angle has annual snow losses of 10% of the annual production, giving only 22.8 million kWh. However, for a tilt angle of 45 degrees, the annual power generated by the system is 24.8 million kWh lower with no snow, which is a drop of 2.3% from what is produced from a 30° tilt. On incorporating the power loss after considering snow losses of 5.2% for a 45° tilt, the resultant annual power generated is actually 2.8% more than from a system with a 30° tilt with snow losses.

The other prominent AC and DC losses in the PV system are typical and default losses in SAM are used for selecting particular inverter types and other system components. As such, the highest loss apart from snow is DC module modeled loss, which is only 3.88%. DC inverter maximum power point tracking, MPPT clipping leads to losses of 0.0403%, while DC mismatch is 1%. DC diode and connections is 0.5%, DC wiring is 1%, DC nameplate loss is 1%, AC inverter power clipping is 0.32%, AC inverter power consumption is 0.27%, AC inverter night tare is 0.04%, AC inverter efficiency loss of 1.59% is used, and AC wiring loss is 1%. Plane of array (POA) shading and soiling is 1.54% and 1%, respectively. As the proposed system is fixed type, DC tracking loss is 0% along with AC step-up transformer and AC performance adjustment losses, which are also 0%. It is assumed that the PV system will be used in next 25 years, but for each year there will be 0.5% annual energy production loss, so the case 1 system will produce about 553 million kWh over its lifetime. This includes 23,487,128 kWh energy produced for the first year and subsequently dropping to 20,824,944 kWh by the 25th year in production.

To give a reasonable picture of monthly snow losses, 5.2% of annual loss of the total produced energy is divided with respect to average snow days in each month for one year. This method gives a fairly good representation as losses in January and December came out to be 25% and 21% alone, as shown in Figure 6. This method can be used for PV systems at airports with less detailed environmental based studies using approximations of losses for the area.



	January	February	March	April	May	June	July	August	September	October	November	December
Total Demand in kWh	48,507	45,590	42,509	35,852	31,336	26,641	33,420	29,280	26,817	29,894	32,837	39,391
Total Produced in kWh	826,269.79	1,492,721.5	2,333,448.5	2,831,683.0	3,236,252.6	2,671,270.0	2,691,350.0	2,926,590.0	2,345,690.0	1,164,447.8	535,601.79	431,802.39

Figure 6. CMX electrical demand for each month vs. solar electrical production (after snow losses) for case study 1 [90].

The comparison between energy production and electric load is shown in Figure 6.

As shown in Figure 6, the energy produced by the relatively small solar PV system for case 1 is substantially higher than the amount of electricity load for each month. The case 1 simulated system produced 23,487,128 kWh in one year compared to the 422,074 kWh demand of the airport, which is more than 5560% of the annual demand. To explain the perspective further, if the actual available land is used which is over 570 acres (case 2), approximately 167,352,321 kWh of power can be yielded, which is more than 396 times the actual annual electrical demand of the existing airport. An important point to note here is that the supply with solar is more than the demand even during the winter days when the demand is highest for the year, and it is also the time when the panels will have maximum losses due to snow and low solar flux. The remainder of the solar generated electricity can be fed to the grid, thus making the net metering credit high as well, along with helping to improve system power quality. An average American household consumes approximately 10,812 kWh of energy [109]. If 570 acres of land is utilized; more than 15,400 households can be benefited directly from it by having 100% of the aggregate electrical use covered by the airport PV system. This is a substantial fraction of the population as it represents roughly half of the county's (Houghton) population.

In addition to the abovementioned examples, solar PV power systems in or around an airport may in fact provide additional advantages. DeVault et al. point out that PV systems do not pose any threat to local biodiversity and, in fact, it is suggested that having solar PV arrays in an airport's vicinity may act as a repellent to birds and thus helping to improve the safety of the airspace [110].

Many of the rural domestic airports are similar to CMX, with huge areas under airport administration and less air traffic. Based on the results achieved here, similar approaches can be applied to other similar airports. This study has shown that it is technically viable to produce significant solar electricity on currently under-utilized airport surface areas. In general PV systems are found to be profitable in much of the U.S., and thus this technical potential provides a substantial business opportunity. In this particular case, residential electric rates are often over US$0.20/kWh in the CMX region. This indicates that case 2 (all safe and acceptable land at CMX) could produce over US$33 million per year in green electricity. As solar PV installations have now dropped below US$1/W costs [111] solar electricity is now widely cost competitive with other forms of electricity generation. Future work is necessary to further analyze the business and legal case for solar PV systems deployed at such airports. Finally, future work is needed to quantify the total potential area for PV system deployment in all the airports in the U.S. and the entire world in terms of PV power, solar electrical production per year, reduced greenhouse gas emissions per year and economic value.

7. Conclusions

This study showed how the technical barriers could be overcome for the large-scale deployment of solar PV in the over 13,000 airports in the U.S. Experimentally measured reflectivity from modern modules is found to agree with theory and is low enough that basic precautions can allow PV safe integration with airports. In addition, this paper summarized how radar interference and the physical penetration of airspace are not major impediments to PV applications at airports. A general approach to implementation of solar PV systems in an airport is provided. The case studies reviewed for a small rural airport show that available land area could not only provide more than 39,000% of the actual annual power demand of the existing airport, but also a significant fraction of the region's electric demand with currently dormant surface areas. Such systems can be of great socioeconomic advantage to the local community given the current costs of grid electricity and the price of PV. Based on the results achieved here, large-scale deployment of PV at airports shows enormous promise.

Acknowledgments: The authors would like to thank CMX airport staff Dennis Hext and Rose Keranen for providing airport information.

Author Contributions: Joshua M. Pearce conceived and designed the study; Anurag Anurag., Jiemin Zhang and Jephias Gwamuri performed the experiments; all authors analyzed the data, wrote and edited the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pearce, J.M. Photovoltaics—A Path to Sustainable Futures. *Futures* **2002**, *34*, 663–674. [CrossRef]
2. Fthenakis, V. Sustainability of photovoltaics: The case for thin-film solar cells. *Renew. Sustain. Energy Rev.* **2009**, *13*, 2746–2750. [CrossRef]
3. Khan, J.; Arsalan, M.H. Solar power technologies for sustainable electricity generation—A review. *Renew. Sustain. Energy Rev.* **2016**, *55*, 414–425. [CrossRef]
4. International Energy Agency (IEA). *Technology Roadmap: Solar Photovoltaic Energy*; IEA: Paris, France, 2014.

5. Alsema, E.A.; Nieuwlaar, E. Energy viability of photovoltaic systems. *Energy Policy* **2000**, *28*, 999–1010. [CrossRef]
6. Hofierka, J.; Kaňuk, J. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. *Renew. Energy* **2009**, *34*, 2206–2214. [CrossRef]
7. Wiginton, L.K.; Nguyen, H.T.; Pearce, J.M. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. *Comput. Environ. Urban Syst.* **2010**, *34*, 345–357. [CrossRef]
8. Nguyen, H.T.; Pearce, J.M.; Harrap, R.; Barber, G. The Application of LiDAR to Assessment of Rooftop Solar Photovoltaic Deployment Potential on a Municipal District Unit. *Sensors* **2012**, *12*, 4534–4558. [CrossRef] [PubMed]
9. Nguyen, H.T.; Pearce, J.M. Automated Quantification of Solar Photovoltaic Potential in Cities. *Int. Rev. Spat. Plan. Sustain. Dev.* **2013**, *1*, 57–70. [CrossRef]
10. De Wild-Scholten, M.J.; Alasema, E.A.; Ter Horst, E.W.; Bachler, M.; Fthenakis, V.M. A Cost and Environmental Impact Comparison of Grid-Connected of Rooftop and Ground Based PV Systems. In Proceedings of the 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4–8 September 2006; pp. 3167–3173.
11. Nguyen, H.T.; Pearce, J.M. Estimating Potential Photovoltaic Yield with r.sun and the Open Source Geographical Resources Analysis Support System. *Sol. Energy* **2010**, *84*, 831–843. [CrossRef]
12. Bolinger, M. *Utility-Scale Solar 2012: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*; U.S. Department of Energy's Solar Energy Technologies Office: Washington, DC, USA, 2014.
13. Fairley, P. Big solar's big surge. *Spectr. IEEE* **2015**, *52*, 41–44. [CrossRef]
14. Izquierdo, S.; Rodrigues, M.; Fueyo, N. A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. *Sol. Energy* **2008**, *82*, 929–939. [CrossRef]
15. Ferrer-Gisbert, C.; Ferrán-Gozálvez, J.J.; Redón-Santafé, M.; Ferrer-Gisbert, P.; Sánchez-Romero, F.J.; Torregrosa-Soler, J.B. A new photovoltaic floating cover system for water reservoirs. *Renew. Energy* **2013**, *60*, 63–70. [CrossRef]
16. Santafé, M.R.; Ferrer Gisbert, P.S.; Sánchez Romero, F.J.; Torregrosa Soler, J.B.; Ferrán Gozálvez, J.J.; Ferrer-Gisbert, C.M. Implementation of a photovoltaic floating cover for irrigation reservoirs. *J. Clean. Prod.* **2014**, *66*, 568–570. [CrossRef]
17. Sacramento, E.M.D.; Carvalho, P.C.M.; Araújo, J.C.; de Riffel, D.B.; Corrêa, R.M.D.C.; Neto, J.S.P. Scenarios for use of floating photovoltaic plants in Brazilian reservoirs. *IET Renew. Power Gener.* **2015**, *9*, 1019–1024. [CrossRef]
18. Trapani, K. Flexible Floating Thin Film Photovoltaic Array Concept for Marine and Lacustrine Environments. Ph.D. Thesis, Laurentian University of Sudbury, Sudbury, ON, Canada, 2014.
19. Majid, Z.A.A.; Ruslan, M.H.; Sopian, K.; Othman, M.Y.; Azmi, M.S.M. Study on Performance of 80 Watt Floating Photovoltaic Panel. *J. Mech. Eng. Sci.* **2014**, *7*, 1150–1156. [CrossRef]
20. Trapani, K.; Redón Santafé, M. A review of floating photovoltaic installations: 2007–2013: A review of floating photovoltaic installations. *Prog. Photovolt. Res. Appl.* **2015**, *23*, 524–532. [CrossRef]
21. Rosa-Clot, M.; Rosa-Clot, P.; Tina, G.M.; Scandura, P.F. Submerged photovoltaic solar panel: SP2. *Renew. Energy* **2009**, *35*, 1862–1865. [CrossRef]
22. Pringle, A.M.; Handler, R.M.; Pearce, J.M. Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture. *Renew. Sustain. Energy Rev.* **2017**, *80*, 572–584. [CrossRef]
23. United Nations Dept. of Economic and Social Affairs. 2014. Available online: http://www.un.org/en/development/desa/population/publications/pdf/trends/Concise%20Report%20on%20the%20World%20Population%20Situation%202014/en.pdf (accessed on 10 April 2015).
24. Nonhebel, S. Renewable Energy and Food Supply: Will There Be Enough Land? *Renew. Sustain. Energy Rev.* **2005**, *9*, 191–201. [CrossRef]
25. Calvert, K.; Pearce, J.M.; Mabee, W.E. Toward renewable energy geo-information infrastructures: Applications of GIScience and remote sensing that can build institutional capacity. *Renew. Sustain. Energy Rev.* **2013**, *18*, 416–429. [CrossRef]

26. Calvert, K.; Mabee, W. More Solar Farms or More Bioenergy Crops? Mapping and Assessing Potential Land-Use Conflicts among Renewable Energy Technologies in Eastern Ontario, Canada. *Appl. Geogr.* **2015**, *56*, 209–221. [CrossRef]
27. Food and Agricultural Organization of the United States of America, "Globally almost 870 million Chronically Undernourished—New Hunger Report". 9 October 2012. Available online: www.fao.org/news/story/en/item/161819/icode/ (accessed on 27 March 2016).
28. Kandt, A.; Romero, R. Implementing Solar Technologies at Airports. NREL Report. Available online: http://www.nrel.gov/docs/fy14osti/62349.pdf (accessed on 30 May 2017).
29. Central Intelligence Agency US, "The World Factbook". Available online: www.cia.gov/library/publications/the-world-factbook/geos/us.html (accessed on 10 September 2016).
30. Airports Master Records and Reports. Available online: http://www.gcr1.com/5010WEB/advancedsearch.cfm (accessed on 28 March 2016).
31. Barrett, S. Glare Factor: Solar Installations and Airports. *Sol. Ind.* **2013**, *6*, 1–4. Available online: http://solarindustrymag.com/online/issues/SI1306/FEAT_02_Glare_Factor.html. (accessed on 10 August 2017).
32. Krishnan, D.S. Bangalore's Airport to Become a Leader in Solar Energy Production. Renewable Energy World. Available online: http://www.renewableenergyworld.com/articles/2016/09/bangalore-s-airport-to-become-a-leader-in-solar-energy-production.html (accessed on 4 October 2016).
33. IND Solar Farm. Available online: www.indsolarfarm.com/the-solar-farm/ (accessed on 30 September 2016).
34. Tuscan Airport Authority. Available online: http://www.flytucson.com/articles/ (accessed on 30 September 2016).
35. CHA solar farm. Available online: http://www.chattairport.com/155.1395/chattanooga-airport-solar-farm/ (accessed on 10 August 2017).
36. Vanasse Hangen Brustlin, Inc., for the San Francisco International Airport Commission, "San Francisco International Airport Environmental Sustainability Report". December 2011. Available online: http://flysfo.proofic.net.s3.amazonaws.com/default/download/about/reports/pdf/SFO_2011_Environmental_Sustainability_Report.pdf (accessed on 30 September 2016).
37. City & County of Denver Department of Aviation. Available online: http://www.flydenver.com/about/administration/ (accessed on 30 September 2016).
38. Branker, K.; Pathak, M.M.; Pearce, J.M. A review of solar photovoltaic levelized cost of electricity. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4470–4482. [CrossRef]
39. Federal Aviation Administration (FAA), "Technical Guidance for Evaluating Selected Solar Technologies on Airports". November 2010; Federal Aviation Administration. Available online: https://www.faa.gov/airports/environmental/policy_guidance/media/airport-solar-guide.pdf (accessed on 30 September 2016).
40. Rogers, J.A.; Ho, C.K.; Mead, A.; Millan, A.; Beben, M.; Drechsler, G. *Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach. Federal Aviation Administration*; Office of Aerspace Medicine: Washington, DC, USA, 2015.
41. Yu, E.T.; Van De Lagemaat, J. Photon management for photovoltaics. *MRS Bull.* **2011**, *36*, 424–428. [CrossRef]
42. Lee, S.H.; Kim, D.H.; Kim, J.H.; Lee, G.S.; Park, J.G. Effect of metal-reflection and surface-roughness properties on power-conversion efficiency for polymer photovoltaic cells. *J. Phys. Chem. C* **2009**, *113*, 21915–21920. [CrossRef]
43. Müller, J.; Rech, B.; Springer, J.; Vanecek, M. TCO and light trapping in silicon thin film solar cells. *Sol. Energy* **2004**, *77*, 917–930. [CrossRef]
44. Berginski, M.; Hüpkes, J.; Schulte, M.; Schöpe, G.; Stiebig, H.; Rech, B.; Wuttig, M. The effect of front ZnO: Al surface texture and optical transparency on efficient light trapping in silicon thin-film solar cells. *J. Appl. Phys.* **2007**, *101*, 074903. [CrossRef]
45. Chen, D. Anti-reflection (AR) coatings made by sol-gel processes: A review. *Sol. Energy Mater. Sol. Cells* **2001**, *68*, 313–336. [CrossRef]
46. Raut, H.K.; Ganesh, V.A.; Nair, A.S.; Ramakrishna, S. Anti-reflective coatings: A critical, in-depth review. *Energy Environ. Sci.* **2011**, *4*, 3779. [CrossRef]
47. Landy, N.I.; Sajuyigbe, S.; Mock, J.J.; Smith, D.R.; Padilla, W.J. Perfect Metamaterial Absorber. *Phys. Rev. Lett.* **2008**, *100*, 207402. [CrossRef] [PubMed]
48. Chen, H.-T. Interference theory of metamaterial perfect absorbers. *Opt. Express* **2012**, *20*, 7165. [CrossRef] [PubMed]

49. Gwamuri, J.; Güney, D.Ö.; Pearce, J.M. Advances in Plasmonic Light Trapping in Thin-Film Solar Photovoltaic Devices. In *Solar Cell. Nanotechnology*; Tiwari, A., Boukherroub, R., Maheshwar Sharon, M., Eds.; Wiley: Hoboken, NJ, USA, 2013; pp. 241–269.
50. Atwater, H.A.; Polman, A. Plasmonics for improved photovoltaic devices. *Nat. Mater.* **2010**, *9*, 205–213. [CrossRef] [PubMed]
51. Ho, C.; Sims, C. *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0*; Sandia National Laboratories: Albuquerque, NM, USA, 23 August 2013.
52. Green, M.A. *Third Generation Photovoltaics*; Springer: New York, NY, USA, 2006.
53. First Solar, Topaz Solar Farm Project Data. Available online: http://www.firstsolar.com/Resources/Projects/Topaz-Solar-Farm (accessed on 10 August 2017).
54. Federal Register, Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports, A Notice by the Federal Aviation Administration, October 2013. Available online: https://www.federalregister.gov/documents/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports (accessed on 8 October 2016).
55. Wittbrodt, B.T.; Pearce, J.M. Total US cost evaluation of low-weight tension-based photovoltaic flat-roof mounted racking. *Sol. Energy* **2015**, *117*, 89–98. [CrossRef]
56. Wittbrodt, B.; Pearce, J.M. 3-D printing solar photovoltaic racking in developing world. *Energy Sustain. Dev.* **2017**, *36*, 1–5. [CrossRef]
57. Dynoraxx, "DynoRaxx Evolution FR Fiberglass Overview". Available online: http://dynoraxx.com/flat-roof-system/evolution-fr/ (accessed on 8 October 2016).
58. Kanzo Inc., KANZO K1250-Polycarbonate PV Rack Structure. Available online: http://www.kanzorack.com/product.html (accessed on 8 October 2016).
59. Schletter.us, "Professional Solar Mounting Systems-Ground Mount Systems". Available online: www.schletter.us (accessed on 8 October 2016).
60. National Geodetic Survey (NGS). Obstruction Identification Surfaces Federal Aviation Regulations Part 77. Available online: www.ngs.noaa.gov/AERO/oisspec (accessed on 8 October 2016).
61. National Renewable Energy Laboratory. Available online: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg (accessed on 8 October 2016).
62. *Air Travel Consumer Report 2015*; US Department of Transportation, Office of Aviation Enforcement and Proceedings: Washington, DC, USA, 2015.
63. Heidari, N.; Gwamuri, J.; Townsend, T.; Pearce, J.M. Impact of Snow and ground interference on photovoltaic electric system performance. *IEEE J. Photovolt.* **2015**, *5*, 1680–1685. [CrossRef]
64. Powers, L.; Newmiller, J.; Townsend, T. Measuring and modeling the effect of snow on photovoltaic system performance. In Proceedings of the 2010 35th IEEE Photovoltaic Specialists Conference (PVSC), Honolulu, HI, USA, 20–25 June 2010; pp. 000973–000978.
65. Townsend, T.; Powers, L. Photovoltaics and snow: An update from two winters of measurements in the sierra. In Proceedings of the 2011 37th IEEE Photovoltaic Specialists Conference (PVSC), Seattle, WA, USA, 19–24 June 2011; pp. 003231–003236.
66. Andrews, R.W.; Pearce, J.M. Prediction of energy effects on photovoltaic systems due to snowfall events. In Proceedings of the 2012 38th IEEE Photovoltaic Specialists Conference (PVSC), Austin, TX, USA, 3–8 June 2012; pp. 003386–003391.
67. Andrews, R.W.; Pollard, A.; Pearce, J.M. The effects of snowfall on solar photovoltaic performance. *Sol. Energy* **2013**, *92*, 84–97. [CrossRef]
68. Andrews, R.W.; Pollard, A.; Pearce, J.M. A new method to determine the effects of hydrodynamic surface coatings on the snow shedding effectiveness of solar photovoltaic modules. *Sol. Energy Mater. Sol. Cells* **2013**, *113*, 71–78. [CrossRef]
69. Andrews, R.W.; Pearce, J.M. The effect of spectral albedo on amorphous silicon and crystalline silicon solar photovoltaic device performance. *Sol. Energy* **2013**, *91*, 233–241. [CrossRef]
70. Los Angeles World Airports, "LAWA Sustainability Report". 2015. Available online: http://www.laxsustainability.org/documents/Sustainability_Report_2015.pdf (accessed on 10 June 2017).
71. National Renewable Energy Lab. System Advisor Model Software (SAM). Available online: https://sam.nrel.gov/ (accessed on 10 June 2017).

72. National Renewable Energy Lab. Solar Prospector. Available online: https://mapsbeta.nrel.gov/nsrdb-viewer/ (accessed on 10 June 2017).
73. National Renewable Energy Lab. Available online: http://pvwatts.nrel.gov/ (accessed on 10 June 2017).
74. Natural Resources Canada. RETScreen. Available online: http://www.nrcan.gc.ca/energy/software-tools/7465 (accessed on 10 June 2017).
75. GRASS GIS. r.sun. Available online: https://grass.osgeo.org/grass73/manuals/r.sun.html (accessed on 10 June 2017).
76. Solarius PV, Solar PV System Design Software. Available online: http://www.accasoftware.com/en/solar-pv-system-design-software/ (accessed 10 August 2017).
77. Teves, J.; Sola, E.F.; Pintor, B.H.; Ang, M.R.C. Assessing the urban solar energy resource potential of Davao City, Philippines, using LiDAR digital surface model (DSM) and GRASS GIS. In Proceedings of the SPIE Remote Sensing, Edinburgh, UK, 26 September 2016; p. 1000809.
78. Araki, I.; Tatsunokuchi, M.; Nakahara, H.; Tomita, T. Bifacial PV system in Aichi Airport-site demonstrative research plant for new energy power generation. *Sol. Energy Mater. Sol. Cells* **2009**, *93*, 911–916. [CrossRef]
79. Messenger, R.; Abtahi, A. *Photovoltaic Systems Engineering*; CRC Press: Boca Raton, FL, USA, 2010.
80. Mukund, R.P. *Wind and Solar Power Systems: Design, Analysis, and Operation*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2006.
81. ArcGIS Pro for Desktop, "An overview of the Solar Radiation tools", 2016. Available online: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/area-solar-radiation.htm (accessed on 10 August 2017).
82. Šúri, M.; Hofierka, J. A new GIS-based solar radiation model and its application to photovoltaic assessments. *Trans. GIS* **2004**, *8*, 8175–8190. [CrossRef]
83. U.S. Census. U.S. Census 2010 Data. Available online: http://www.census.gov/2010census/data/ (accessed on 10 June 2017).
84. Shah, K.K.; Mundada, A.; Pearce, J.M. Performance of US hybrid distributed energy systems: Solar photovoltaic, battery and combined heat and power. *Energy Convers. Manag.* **2015**, *105*, 71–80. [CrossRef]
85. Dubey, S.; Sarvaiya, J.N.; Seshadri, B. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world—A review. *Energy Procedia* **2013**, *33*, 311–321. [CrossRef]
86. Kantamneni, A.; Winkler, R.; Gauchia, L.; Pearce, J.M. Emerging economic viability of grid defection in a northern climate using solar hybrid systems. *Energy Policy* **2016**, *95*, 378–389. [CrossRef]
87. Keweenaw Research Center. Available online: http://www.appropedia.org/KRC_data:MOST (accessed on 10 June 2017).
88. Wilcox, S. *National Solar Radiation Database 1991–2005 Update: User's Manual*; No. NREL/TP-581-41364; National Renewable Energy Laboratory (NREL): Golden, CO, USA, 2007.
89. Hext, D.M. *Via Personal Communication and Data Sharing Regarding Electric Bills and Airport Land Property*; Houghton County Memorial Airport: Houghton County, MI, USA, 2015.
90. Hecht, E.; Zajac, A. *Optics 4th (International) Edition*; Addison Wesley Publishing Company: Boston, MA, USA, 2002; ISBN:0-321-18878-0..
91. Xi, J.Q.; Kim, J.K.; Schubert, E.F. Silica nanorod-array films with very low refractive indices. *Nano Lett.* **2005**, *5*, 1385–1387. [CrossRef] [PubMed]
92. Xi, J.Q.; Schubert, M.F.; Kim, J.K.; Schubert, E.F.; Chen, M.; Lin, S.Y.; Liu, W.; Smart, J.A. Optical thin-film materials with low refractive index for broadband elimination of Fresnel reflection. *Nat. Photonics* **2007**, *1*, 176–179.
93. Yan, X.; Poxson, D.J.; Cho, J.; Welser, R.E.; Sood, A.K.; Kim, J.K.; Schubert, E.F. Enhanced Omnidirectional Photovoltaic Performance of Solar Cells Using Multiple-Discrete-Layer Tailored-and Low-Refractive Index Anti-Reflection Coatings. *Adv. Funct. Mater.* **2013**, *23*, 583–590. [CrossRef]
94. Kuo, M.L.; Poxson, D.J.; Kim, Y.S.; Mont, F.W.; Kim, J.K.; Schubert, E.F.; Lin, S.Y. Realization of a near-perfect antireflection coating for silicon solar energy utilization. *Opt. Lett.* **2008**, *33*, 2527–2529. [CrossRef] [PubMed]
95. Chang, C.H.; Yu, P.; Yang, C.S. Broadband and omnidirectional antireflection from conductive indium-tin-oxide nanocolumns prepared by glancing-angle deposition with nitrogen. *Appl. Phys. Lett.* **2009**, *94*, 051114. [CrossRef]

96. Yu, P.; Chang, C.H.; Chiu, C.H.; Yang, C.S.; Yu, J.C.; Kuo, H.C.; Hsu, S.H.; Chang, Y.C. Efficiency enhancement of GaAs photovoltaics employing antireflective indium tin oxide nanocolumns. *Adv. Mater.* **2009**, *21*, 1618–1621. [CrossRef]
97. Shea, S.P. Evaluation of Glare Potential for Photovoltaic Installations, 2012. Available online: http://www.suniva.com/documents/Suniva%20Reflection%20and%20Glare%20Report%20-%20Marketing%20-%20August%202012.pdf (accessed on 8 October 2016).
98. Ho, C.K.; Sims, C.A.; Yellowhair, J.; Bush, E. Solar Glare Hazard Analysis Tool (SGHAT) Technical Reference Manual. 2015. Available online: https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Technical_Reference-v5.pdf (accessed on 10 June 2017).
99. Ruesch, F.; Bohren, A.; Battaglia, M.; Brunold, S. Quantification of Glare from Reflected Sunlight of Solar Installations. *Energy Procedia* **2016**, *91*, 997–1004. [CrossRef]
100. Barrett, S.; Devita, P.; Ho, C.; Miller, B. Energy technologies' compatibility with airports and airspace: Guidance for aviation and energy planners. *J. Airpt. Manag.* **2014**, *8*, 318–326.
101. Nguyen, T.V.; Ariza, A.F.; Miller, N.W.; Cremer, I. *A Framework for the Development of Technical Requirements for Renewable Energy Systems at a Small-Scale Airport Facility. Proceedings of ASME 2015 9th International Conference on Energy Sustainability Collocated with the ASME 2015 Power Conference, the ASME 2015 13th International Conference on Fuel Cell Science, Engineering and Technology, and the ASME 2015 Nuclear Forum, San Diego, CA, USA, 28 June–2 July 2015*; American Society of Mechanical Engineers: New York, NY, USA, 2015; Volume 2, p. V002T16A004.
102. Mostafa, M.F.; Aleem, S.H.A.; Zobaa, A.F. December. Risk assessment and possible mitigation solutions for using solar photovoltaic at airports. In *Power Systems Conference (MEPCON), 2016 Eighteenth International Middle East*; IEEE: New Jersey, NJ, USA, 2016; pp. 81–88.
103. Forge Solar Subscription Plans. Available online: https://www.forgesolar.com/pricing/ (accessed on 13 June 2017).
104. Balter, B. Why Isn't All Government Software Open Source? 2014. Available online: https://opensource.com/government/14/8/why-isnt-all-government-software-open-source (accessed on 13 June 2017).
105. Finlyey, K. OPEN SOURCE WON. SO, NOW WHAT? Wired. 2015. Available online: https://www.wired.com/2016/08/open-source-won-now/ (accessed on 13 June 2017).
106. Pearce, J.M. Physics: Make nanotechnology research open-source. *Nature* **2012**, *491*, 519–521. [PubMed]
107. Pearce, J.M. Quantifying the Value of Open Source Hardware Development. *Mod. Econ.* **2015**, *6*, 1–11. [CrossRef]
108. Pearce, J.M. Return on Investment for Open Source Hardware Development. *Sci. Public Policy* **2016**, *43*, 192–195. [CrossRef]
109. U.S Energy Information Administration, October 2016. Available online: https://www.eia.gov/tools/faqs (accessed on 13 June 2017).
110. DeVault, T.L.; Seamans, T.W.; Schmidt, J.A.; Belant, J.L.; Blackwell, B.F.; Mooers, N.; Tyson, L.A.; Pelt, L.V. Bird use of solar photovoltaic installations at US airports: Implications for aviation safety. *Landsc. Urban Plan.* **2014**, *122*, 122–128. [CrossRef]
111. Roselund, C. Utility-Scale Solar Falls Below $1 Per Watt (w/charts). PV Magazine 2017. Available online: https://pv-magazine-usa.com/2017/06/12/utility-scale-solar-falls-below-1-per-watt/ (accessed on 13 June 2017).

Exhibit G

Clean Energy Results: Questions & Answers Ground-Mounted Solar Photovoltaic Systems

CLEANENERGYRESULTS

Questions & Answers

Ground-Mounted Solar Photovoltaic Systems

Westford Solar Park, photo courtesy of EEA

June 2015

Massachusetts Department of Energy Resources
Massachusetts Department of Environmental Protection
Massachusetts Clean Energy Center

Table of Contents

Background

Encouraging increased use of solar photovoltaic (PV) technology, which converts sunlight directly into electricity, is a key priority for state clean energy efforts. The environmental benefits of solar PV abound. Unlike conventional fossil fuel power generation (such as coal, gas and oil), generating electricity with ground-mounted solar PV involves no moving parts, uses no water, and produces no direct emissions of climate-warming greenhouse gases.

Solar PV environmental and energy benefits, combined with strong incentives available for solar projects, have significantly increased the use of this technology recently. The Commonwealth's vibrant solar industry has a variety of ownership and financing options for Massachusetts residents and businesses looking to install solar PV systems. Purchasing a solar PV system generally involves upfront installation and equipment costs, but there are significant upfront and production-based incentives[1].

As the Massachusetts clean energy sector grows, the Baker Administration is working to ensure that solar PV and other clean energy technologies are sited in a way that is most protective of human health and the environment, and minimizes impacts on scenic, natural, and historic resources.

Purpose of Guide

This guide is intended to help local decision-makers and community members answer common questions about ground-mounted solar PV development. Ground-mounted solar PV has many proven advantages and there has been a steady growth of well received projects in the Commonwealth. However, these systems are still relatively new and unfamiliar additions to our physical landscape.

This guide focuses on questions that have been raised concerning the installation and operation of ground-mounted solar PV projects. It provides summaries and links to existing research and studies that can help understand solar PV technology in general and ground-mounted solar in particular.

Solar PV panels can and are of course also installed on buildings[2], car ports or light poles. This guide focuses on ground-mounted systems since most questions relate to this type of solar installation.

Developed through the partnership of the Massachusetts Department of Energy Resources (DOER), the Massachusetts Department of Environmental Protection (MassDEP), and the Massachusetts Clean Energy Center (MassCEC), this guide draws from existing recent literature in the United States and abroad and is not the result of new original scientific studies. The text was reviewed by the National Renewable Energy Laboratory (NREL).

As more or new information becomes available, the guide will be updated and expanded accordingly.

---

[1] For a comprehensive overview, start at http://masscec.com/index.cfm/page/Solar-PV/pid/12584

[2] For an overview of the multiple options for siting PV and buildings in the same footprint, see the Solar Ready Buildings Planning Guide, NREL, 2009.

Solar PV Projects Are Sited Locally

The siting authority for solar PV projects resides at the local - not the state - level. One purpose of this guide is to inform and facilitate local efforts to expand clean energy generation in a sustainable way, and provide a consolidated source of existing research and information that addresses common questions faced by communities.

As part of the Green Communities Act of 2008, DOER and the Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) developed a model zoning by-law/ordinance called "as-of-right siting" that does not require a special permit. It is designed to help communities considering adoption of zoning for siting of large-scale solar. This model zoning by-law/ordinance provides standards for the placement, design, construction, operation, monitoring, modification and removal of new large-scale ground-mounted solar PV installations. The latest version of the model by-law was published in December 2014[3]. It provides useful information that will not be repeated extensively in this guide.

Consider Impacts of Other Possible Developments at Site

Use of land for the purpose of solar photovoltaic power generation should be compatible with most other types of land usage. However, DOER strongly discourages designating locations that require significant tree cutting because of the important water management, cooling and climate benefits trees provide. DOER encourages designating locations in industrial and commercial districts, or on vacant, disturbed land.

When assessing the impact of new ground-mounted solar arrays, communities and other stakeholders should carefully consider other types of development that might take place in a particular location if there was no solar installation. Stakeholders should bear in mind the higher or lower impacts that those alternatives might have in terms of noise, air pollution or landscape. These alternative impacts fall outside the scope of this guide, but are relevant when looking at individual projects.

[3] http://www.mass.gov/eea/docs/doer/green-communities/grant-program/model-solar-zoning.pdf

Hazardous Materials

The Question: What, if any, health risks do chemicals used to manufacture solar panels and other devices used in solar PV arrays pose if they are released into the environment?

Bottom Line: Because PV panel materials are enclosed, and don't mix with water or vaporize into the air, there is little, if any, risk of chemical releases to the environment during normal use. The most common type of PV panel is made of tempered glass, which is quite strong. They pass hail tests, and are regularly installed in Arctic and Antarctic conditions. Only in the unlikely event of a sufficiently hot fire is there a slight chance that chemicals could be released. This is unlikely because most residential fires are not hot enough to melt PV components and PV systems must conform to state and federal fire safety, electrical and building codes.

Transformers used at PV installations, that are similar to the ones used throughout the electricity distribution system in cities and towns, have the potential to release chemicals if they leak or catch fire. Transformer coolants containing halogens have some potential for toxic releases to the air if combusted. However, modern transformers typically use non-toxic coolants, such as mineral oils. Potential releases from transformers using these coolants at PV installations are not expected to present a risk to human health.

More Information: Ground-mounted PV solar arrays are typically made up of panels of silicon solar cells covered by a thin layer of protective glass, which is attached to an inert solid underlying substance (or "substrate"). While the vast majority of PV panels currently in use are made of silicon, certain types of solar cells may contain cadmium telluride (CdTe), copper indium diselenide (CIS), and gallium arsenide (GaAs).

All solar panel materials, including the chemicals noted above, are contained in a solid matrix, insoluble and non-volatile at ambient conditions, and enclosed. Therefore, releases to the ground from leaching, to the air from volatilization during use, or from panel breakage, are not a concern. Particulate emissions could only occur if the materials were ground to a fine dust, but there is no realistic scenario for this. Panels exposed to extremely high heat could emit vapors and particulates from PV panel components to the air. However, researchers have concluded that the potential for emissions derived from PV components during typical fires is limited given the relatively short-duration of most fires and the high melting point (>1000 degrees Celsius) of PV materials compared to the roof level temperatures typically observed during residential fires (800-900 degrees Celsius). In the rare instance where a solar panel might be subject to higher temperatures, the silicon and other chemicals that comprise the solar panel would likely bind to the glass that covers the PV cells and be retained there.

Release of any toxic materials from solid state inverters is also unlikely provided appropriate electrical and installation requirements are followed. For more information on public safety and fire, see the Public Safety section of this document.

We should also note that usually the rain is sufficient to keep the panels clean, so no extra cleaning in which cleaning products might be used, is necessary.

Resources:

Fthenakis, V.M., Overview of Potential Hazards in *Practical Handbook of Photovoltaics: Fundamentals and Applications, General editors T. Markvart and L. Castaner, to be published by Elsevier in 2003*.

Fthenakis, V.M. Life cycle impact analysis of cadmium in CdTe PV production. Renewable and Sustainable Energy Reviews 8, 303-334, 2004.

Fthenakis V.M., Kim H.C., Colli A., and Kirchsteiger C., Evaluation of Risks in the Life Cycle of Photovoltaics in a Comparative Context, 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4-8 September 2006.

Moskowitz P. and Fthenakis V., Toxic materials released from photovoltaic modules during fires; health risks, Solar Cells, 29, 63-71, 1990.

Sherwani, A.F., Usmani, J.A., & Varun. Life cycle assessment of solar PV based electricity generation systems: A review. Renewable and Sustainable Energy Reviews. 14, 540-544, 2010.

Zayed, J; Philippe, S (2009-08). "Acute Oral and Inhalation Toxicities in Rats With Cadmium Telluride" (PDF). *International journal of toxicology* (International Journal of Toxicology) **28** (4): 259–65. doi:10.1177/1091581809337630. PMID 19636069. http://ijt.sagepub.com/cgi/content/short/28/4/259.

End-of-Life/Decommissioning

Question: How do I manage solar panels after they are decommissioned and no longer in use? Can they be recycled and do hazardous waste disposal requirements apply?

Bottom Line: As more solar panels are decommissioned interest in recycling the panels has increased in Europe and the U.S. Massachusetts regulations ensure proper disposal and recycling of panels if they have components that constitute solid or hazardous waste under state regulations.

More information: The average life of solar PV panels can be 20-30 years (or longer) after initial installation. PV cells typically lose about 0.5% of their energy production capacity per year. At the time of decommissioning, panels may be reused, recycled or disposed. Since widespread use of solar PV is recent in Massachusetts, only a small percentage of solar panels in use in the state have had to be replaced due to damage or reached the end of their useful lifetime. A significant increase in the amount of end-of-life PV modules is expected over the next few decades.

When solar panels are decommissioned and discarded, state rules require that panel disposal be "properly managed" pursuant to the Massachusetts hazardous waste regulations, 310 CMR 30.000. There are many different types of solar panels used in ground-mounted or roof mounted solar PV systems; some of these panels have components that may require special hazardous waste disposal or recycling. Solar module manufacturers typically provide a list of materials used in the manufacturing of their product, which may be used to determine the proper disposal requirements at the time of decommissioning. Under the hazardous waste regulations, the burden is on the generator of the panels to determine if the waste being generated (the solar panels) is hazardous or not. This determination can be made using "knowledge" (i.e. an MSDS sheet listing the materials used in manufacture of the panels) or testing (i.e. the Toxicity Characteristic Leaching Procedure – TCLP).

If a panel is tested and passes TCLP then it is regulated as a solid waste; if it fails TCLP then it is regulated as a hazardous waste.

However, if the solar panel is determined to be hazardous due solely to the presence of metal-bearing circuit boards, the panels may be conditionally exempt from the hazardous waste regulations if destined for recycling. See 310 CMR 30.202(5)(d)-(e) in the Mass. Hazardous Waste Regulations.[4]

People who lease land for solar projects are encouraged to include end-of-life panel management as part of the lease. In cases where panels are purchased, owners need to determine whether the end-of

[4] (5) The following materials are not subject to 310 CMR 30.200, or any other provision of 310 CMR 30.000:

(d) Whole used circuit boards being recycled provided they are free of mercury switches, mercury relays, nickel-cadmium batteries, or lithium batteries.

(e) Shredded circuit boards being recycled provided that they are:

1. managed in containers sufficient to prevent a release to the environment prior to recovery; and,

2. free of mercury switches, mercury relays and nickel-cadmium batteries and lithium batteries.

life panels are a solid or hazardous waste and dispose or recycle the panels appropriately. Massachusetts regulations require testing of waste before disposal.

Because of the various materials used to produce solar panels (such as metal and glass), interest in recycling of solar modules has grown. Throughout Europe, a not-for-profit association (PV Cycle) is managing a voluntary collection and recycling program for end-of-life PV modules. The American photovoltaic industry is not required by state or federal regulation to recycle its products, but several solar companies are starting to recycle on a voluntary basis. Some manufacturers are offering end-of-life recycling options and independent companies looking to recycle solar modules are growing. This allows for the recycling of the PV panels and prevents issues with the hazardous materials. Currently, the California Department of Toxic Substances Control is considering standards for the management of solar PV panels at the end of their use.

DOER's model zoning provides language on requirements for abandonment and decommissioning of solar panels for use by local officials considering local approvals for these projects.

Resources

End-of-life PV: then what? - Recycling solar PV panels
http://www.renewableenergyfocus.com/view/3005/end-of-life-pv-then-what-recycling-solar-pv-panels/

MassDEP Hazardous Waste Regulations 310 CMR 30.000
http://www.mass.gov/eea/agencies/massdep/recycle/regulations/310-cmr-30-000.html

PV Cycle, Europe: http://www.pvcycle.org/

California Department of Toxic Substances Control, Proposed Standards for the Management of Hazardous Waste Solar Modules,
http://www.dtsc.ca.gov/LawsRegsPolicies/Regs/Reg_Exempt_HW_Solar_Panels.cfm

Ambient Temperature ("Heat Island")

The Question: Does the presence of ground-mounted solar PV arrays cause higher ambient temperatures in the surrounding neighborhood (i.e., the "heat island" effect)?

Bottom Line: All available evidence indicates that there is no solar "heat island" effect caused by the functioning of solar arrays. Cutting shade trees for solar PV might increase the need for cooling if those trees were shading buildings. This is primarily a concern in town centers and residential areas (locations where large ground-mounted PV is not encouraged) and is a potential impact of any development activity that requires tree-cutting.

More Information: All available evidence indicates that there is no solar "heat island" effect caused by the functioning of solar arrays. Solar panels absorb photons from direct sunlight and convert it to electricity. This minimizes the likelihood of substantially changing temperatures at the site or the surrounding neighborhood. For an area with no PV system, solar energy impacting the ground is either reflected or absorbed. There is no research to support heat production from the solar panels themselves.

Sunpower, a private solar manufacturer, conducted a study on the impact of solar PV on the local temperature, and concluded that a solar PV array can absorb a higher percentage of heat than a forested parcel of land without an array. The study points out that while solar PV modules can reach high operating temperatures up to 120 degrees Fahrenheit, they are thin and lightweight and therefore do not store a large amount of heat. Because of this, and the fact that panels are also shown to cool to ambient air temperature shortly after the sun sets, the Sunpower study concludes that the area surrounding a large-scale solar array is unlikely to experience a net heating change from the panels.

If trees are removed that were previously shading a building, that building could get warmer in full sunshine than when the trees were shading it. The June 1, 2011 tornado that ripped through Western Massachusetts created an opportunity to empirically measure the effects of the loss of neighborhood trees on temperatures and air humidity in the streets. A report by the U.S. Department of Agriculture Forest Service concluded that daily mean morning and afternoon temperatures were typically greater in the tornado-impacted neighborhood in Springfield, Massachusetts than in the unaffected neighborhood and forest sites, but were similar at night. Residents noted increased use of air-conditioning units and an overall increase in energy costs in July and August of 2011.

Resources:

SUNPOWER, Impact of PV Systems on Local Temperature, July 2010

USDA Forest Services report: http://www.regreenspringfield.com/wp-content/uploads/2011/11/tornado%20climate%20report%203.pdf

Electric and Magnetic Fields (EMF)

The Question: What, if any, health risks do the electric and magnetic fields (EMF) from solar panels and other components of solar PV arrays pose?

Bottom Line: Electric and magnetic fields are a normal part of life in the modern world. PV arrays generate EMF in the same extremely low frequency (ELF) range as electrical appliances and wiring found in most homes and buildings. The average daily background exposure to magnetic fields is estimated to be around one mG (milligauss – the unit used to measure magnetic field strength), but can vary considerably depending on a person's exposure to EMF from household electrical devices and wiring. The lowest exposure level that has been potentially associated with a health effect is three mG. Measurements at three commercial PV arrays in Massachusetts demonstrated that their contributions to off-site EMF exposures were low (less than 0.5 mG at the site boundary), which is consistent with the drop off of EMF strength based on distance from the source.

More Information: Solar PV panels, inverters and other components that make up solar PV arrays produce extremely low frequency EMF when generating and transmitting electricity. The extremely low frequency EMF from PV arrays is the same as the EMF people are exposed to from household electrical appliances, wiring in buildings, and power transmission lines (all at the power frequency of 60 hertz). EMF produced by cell phones, radios and microwaves is at much higher frequencies (30,000 hertz and above).

Electric fields are present when a device is connected to a power source, but are shielded or blocked by common materials, resulting in low potential for exposures. On the other hand, magnetic fields, which are only generated when a device is turned on, are not easily shielded and pass through most objects, resulting in greater potential for exposure. Both types of fields are strongest at the source and their strength decreases rapidly as the distance from the source increases. For example, the magnetic field from a vacuum cleaner six inches away from the motor is 300 mG and decreases to two mG three feet away. People are exposed to EMF during normal use of electricity and exposure varies greatly over time, depending on the distance to various household appliances and the length of time they are on. The daily average background level of magnetic fields for US residents is one mG.

EMF from PV Arrays: Solar PV panels produce low levels of extremely low frequency (ELF) EMF, with measured field strengths of less than one mG three inches from the panel. Solar PV power inverters, transformers and conduits generate higher levels of ELF-EMF. The amount of ELF-EMF is proportional to the electrical capacity of the inverter and is greater when more current (electricity) is flowing through a power line.

In a study of two PV arrays (using 10-20 kW invertors) in Kerman and Davis, California, the magnetic field was highest at the inverters and transformers, but decreased rapidly to less than one mG within 50 feet of the units, well within the boundary of the PV array (Chang and Jennings 1994). This data indicates that extremely low frequency EMF field strengths at residences near systems of this size would be below the typical levels experienced by most people at home. The highest extremely low frequency EMF (up to 1,050 mG) was found next to an inverter unit at the point of entry of the electrical conduits. Even this value is less than the extremely low frequency EMF reported for some common household devices such as an electric can opener with a maximum of 1500 mG at 6 inches.

In a recent study of three ground mounted PV arrays in Massachusetts, the above results were confirmed. The PV arrays had a capacity range of 1 to 3.5 MW. Magnetic field levels along the PV array site boundary were in the very low range of 0.2 to 0.4 mG. Magnetic fields at 3 to 7 feet from the inverters ranged from 500 to 150 mG. At a distance of 150 feet from the inverters, these fields dropped back to very low levels of 0.5 mG or less, and in many cases to much less than background levels (0.2 mG).

Potential Health Effects: Four research studies have reported an association between three to four mG EMF exposure and childhood leukemia, while 11 other studies have not. These studies are inconsistent and do not demonstrate a causal link that would trigger a World Health Organization (WHO) designation of EMF as a possible carcinogen[5]. Studies looking at other cancers in humans and animals have not found evidence of a link to residential ELF-EMF exposure.

Reference Exposure Levels: To protect the general public from health effects from short-term high level magnetic fields, the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010) advised an exposure limit for extremely low frequency magnetic fields at 2000 mG. ICNIRP determined that the evidence on the impact of long-term exposure to low level magnetic fields was too uncertain to use to set a guideline. Guidelines for the magnetic field allowed at the edge of transmission line right-of-ways have been set at 200 mG by Florida and New York. Exposure to magnetic fields greater than 1000 mG is not recommended for people with pacemakers or defibrillators (ACGIH, 2001).

Resources:

American Conference of Government Industrial Hygienist (ACGIH). 2001. as cited in NIEHS 2002.

Chang, GJ and Jennings, C. 1994. Magnetic field survey at PG&E photovoltaic sites. PG&E R&D Report 007.5-94-6.

Electric Power Research Institute (EPRI). 2012. EMF and your health. http://my.epri.com/portal/server.pt?Abstract_id=000000000001023105.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 2010. ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100kHz). Health Physics 99(6):818-836.

National Cancer Institute (NCI). 2005. Magnetic Field Exposure and Cancer: Questions and Answers. U.S. Department of Health and Human Services, National Institutes of Health. Available http://www.cancer.gov/cancertopics/factsheet/Risk/magnetic-fields, accessed May 14, 2012.

[5] WHO has designated ELF-EMF as a possible carcinogen. The use of the label "possible carcinogen" indicates that there is not enough evidence to designate ELF-EMF as a "probable carcinogen "or "human carcinogen," the two indicators of higher potential for being carcinogenic in humans.

National Institute of Environmental Health Science (NIEHS) 2002. Electric and Magnetic Fields Associated with the Use of Electric Power: Questions and Answers. Available http://www.niehs.nih.gov/health/assets/docs_p_z/results_of_emf_research_emf_questions_answers_booklet.pdf, accessed May 11, 2012.

National Institute of Environmental Health Science (NIEHS) web page on EMF. Available http://www.niehs.nih.gov/health/topics/agents/emf/, accessed May 11, 2012.

Oregon Department of Transportation (Oregon DOT). Scaling public concerns of electromagnetic fields produced by solar photovoltaic arrays. Produced by Good Company for ODOT for the West Linn Solar Highway Project. Available www.oregon.gov/ODOT/HWY/OIPP/docs/emf**concerns**.pdf.

World Health Organization (WHO). 2007. Electromagnetic fields and public health: Exposure to extremely low frequency fields. Fact sheet N°322. June 2007. Available http://www.who.int/mediacentre/factsheets/fs322/en/index.html, accessed May 16, 2012. This fact sheet provides a short summary of the in-depth review documented in the WHO 2007, Environmental Health Criteria 238. Available http://www.who.int/peh-emf/publications/elf_ehc/en/index.html.

Property Values

Question: How do ground-mounted solar PV arrays adjacent to residential neighborhoods influence the property values in those neighborhoods?

Bottom Line: No research was found specific to ground-mounted solar PV and property values. Residential property value research on roof-mounted solar PV and wind turbines illustrates no evidence of devaluation of homes in the area. Municipalities that adopt zoning for solar facilities may want to consider encouraging project developers to include screening vegetation along site borders to minimize visual impacts on surrounding neighborhoods.

More Information: A review of literature nationwide shows little evidence that solar arrays influence nearby property values. An analysis focused on roof-mounted solar PV done by the U.S. Department of Energy Lawrence Berkeley National Laboratory concludes that household solar installation actually increases home property values. This research analyzes a large dataset of California homes that sold from 2000 through mid-2009 with PV installed. Across a large number of repeat sales model specifications and robustness tests, the analysis finds strong evidence that California homes with PV systems have sold for a premium over comparable homes without PV systems.

Resources:

An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California
http://emp.lbl.gov/sites/all/files/lbnl-4476e.pdf

Public Safety (including fires)

Question: What public safety issues arise from people's (including children) access to areas where solar arrays are installed? Can electrical and other equipment associated with solar projects cause electrical fires?

Bottom Line: Large-scale ground-mounted arrays are typically enclosed by fencing. This prevents children and the general public from coming into contact with the installations, thus preventing unsafe situations. The National Electric Code has mandatory requirements to promote the electrical safety of solar PV arrays. Emergency personnel responding to potential emergencies at a solar PV site face the most risk, but the solar industry and firefighters provide training and education for emergency personnel to ensure that the proper safety precautions are taken.

More Information: The National Electric Code has mandatory requirements for the electrical safety of solar PV arrays. To protect against intruders, Article 690 of the National Electric Code covers the safety standards for solar PV installation and requires that conductors installed as part of solar PV be "not readily accessible". With a large-scale ground-mounted array, a fence is typically installed around the system to prevent intruders. Some communities have solar PV or signage by-laws that require identification of the system owner and 24-hour emergency contact information.

DOER's Model by-Law/ordinance requires owners of solar PV facilities to provide a copy of the project summary, electrical schematic, and site plan to the local fire chief, who can then work with the owner and local emergency services to develop an emergency response plan.

These measures can be combined with products to prevent theft of the panels. Some are very low cost options (fastener type) while there are other options that are more expensive (alarm system type) but also more effective. The biggest potential risk associated with solar PV systems is the risk of shock or electrocution for firefighters and other emergency responders who could come in contact with high voltage conductors. A 2010 study on firefighter safety and emergency response for solar PV systems by the Fire Protection Research Foundation, based in Quincy, Massachusetts, recommended steps firefighters can take when dealing with wiring and other components that may be energized. The Solar Energy Business Association of New England (SEBANE) has been working to provide training and education to first-responders to identify and avoid potential hazards when responding to a solar PV fire.

For more information about toxics/fires, see the Hazardous Materials Section.

Resources:

Moskowitz, P.D. and Fthenakis, V.M., Toxic Materials Released from Photovoltaic Modules During Fires: Health Risks, Solar Cells, 29, 63-71, 1990. 21.

Solar America Board for Codes and Standards
http://www.solarabcs.org/about/publications/reports/blindspot/pdfs/BlindSpot.pdf

Fire Fighter Safety and Emergency Response for Solar Power Systems: Final Report, May 2010. Prepared by The Fire Protection Research Foundation

National Electric Code Article 250: Grounding and Bonding, Article 300: Wiring Methods, Article 690 Solar PV Systems, Article 705 Interconnected Electric Power Production Sources

Historic Preservation

The Question: What are the appropriate standards when land with historical or archaeological significance is developed for large-scale solar PV arrays?

Bottom Line: Parties undertaking solar PV projects with state or federal agency involvement must provide the Massachusetts Historical Commission (MHC) with complete project information as early as possible in the planning stage, by mail to the MHC's office (see Resources). Parties should also contact local planning, historical or historic district commissions to learn about any required local approvals. Municipalities should also take the presence of historic resources into account when establishing zoning regulations for solar energy facilities in order to avoid or minimize impacts.

More Information: Land being evaluated for the siting of large-scale solar PV has historical or archaeological significance including properties listed in the National or State Registers of Historic Places and/or the Inventory of Historic and Archaeological Assets of the Commonwealth.

Federal and state laws require that any new construction, demolition or rehabilitation projects (including new construction of solar PV) that propose to use funding, licenses or permits from federal or state government agencies must be reviewed by the MHC so that feasible alternatives are developed and implemented to avoid or mitigate any adverse effects to historic and archaeological properties. Projects receiving federal funding, licenses or permits are reviewed by the involved federal agency in consultation with the MHC and other parties in compliance with Section 106 of the National Historic Preservation Act of 1966 (16 U.S.C. 470f) and the implementing regulations (36 CFR 800) in order to reach agreement to resolve any adverse effects. Projects receiving state funding, licenses or permits must notify the MHC in compliance with M.G.L. c. 9, ss. 26-27C and the implementing regulations 950 CMR 71. If the MHC determines that the project will have an adverse effect, the involved state agency, the project proponent, the local historical preservation agencies, and other interested parties consult to reach an agreement that outlines measures to be implemented to avoid, minimize, or mitigate adverse effects. For projects with both federal and state agency involvement, the Section 106 process is used.

Some communities have local preservation ordinances or established local historic districts that require local approval for new construction visible from a public way. Local historic district commissions have adopted design guidelines for new construction within their historic districts and historic neighborhoods. However, these guidelines must account for Chapter 40C Section 7 of the General Laws, which requires a historic district commission to consider the policy of the Commonwealth to encourage the use of solar energy systems and to protect solar access.

Resources:

Federal Agency Assisted Projects:

Section 106 review information and the federal regulations 36 CFR 800 are available at the Advisory Council on Historic Preservation (ACHP) web site: www.achp.gov. Check with the involved federal agency for how they propose to initiate the MHC notification required by 36 CFR 800.3.

State Agency Assisted Projects:

Massachusetts General Laws Chapter 9, sections 26-27C

MHC Regulations 950 CMR 71 (available from the State House Bookstore)

MHC Review & Compliance FAQs http://www.sec.state.ma.us/mhc/mhcrevcom/revcomidx.htm

MHC Project Notification Form (PNF) & Guidance for Completing the PNF and required attachments (USGS locus map, project plans, current photographs keyed to the plan). Mail or deliver the complete project information to the MHC's office: http://www.sec.state.ma.us/mhc/mhcform/formidx.htm

General Guidance about Designing Solar PV Projects on Historic Buildings and in Historic Areas: http://www.nrel.gov/docs/fy11osti/51297.pdf

Noise

Question: Do the inverters, transformers or other equipment used as part of ground-mounted solar PV create noise that will impact the surrounding neighborhood?

Bottom Line: Ground-mounted solar PV array inverters and transformers make a humming noise during daytime, when the array generates electricity. At 50 to 150 feet from the boundary of the arrays, any sound from the inverters is inaudible. Parties that are planning and designing ground-mounted solar PV should explore options to minimize noise impacts to surrounding areas. This could include conducting pre-construction sound studies, evaluating where to place transformers, and undertaking appropriate noise mitigation measures.

More Information: Most typically, the source of noise associated with ground-mounted solar PV comes from inverters and transformers. There also may be some minimal noise from switching gear associated with power substations. The crackling or hissing sound caused by high-voltage transmission lines (the “Corona Effect”) is not a concern in the case of solar PV, which uses lower voltage lines.

Parties siting ground-mounted solar PV projects should consult equipment manufacturers to obtain information about sound that can be expected from electrical equipment, since this can vary. For example, according to manufacturer’s information, a SatCon Powergate Plus 1 MW Commercial Solar PV Inverter has an unshielded noise rating of 65 decibels (dBA) at five feet. This is approximately the sound equivalent of having a normal conversation with someone three feet away. Another source of information is the National Electrical Manufacturers Association (NEMA) standards, which will provide maximum sound levels from various equipment arrays. From NEMA, a large dry-type transformer (2001-3333 kVA) that is forced air cooled and ventilated has an average sound level of 71 dBA, which is approximately the sound level one would expect from a vacuum cleaner at ten feet. There may be several such units on a substantially sized PV site, which would increase the sound level to some degree.

Sound impacts from electrical equipment can be modeled to the property line or nearest sensitive receptor (residence). Sound impacts can be mitigated with the use of enclosures, shielding and careful placement of the sound-generating equipment on-site. The rule of thumb for siting noise-generating equipment is that the sound impact can be reduced by half by doubling the distance to the receptor.

In some areas both in the US and Canada, sound impact analysis is required as part of the permitting process for large PV systems. For example, in the Province of Ontario, Canada, any project greater than 12 MW is required to perform a sound impact analysis (Ontario 359/09). California also requires a sound impact analysis for large PV projects. Massachusetts currently has no such requirement, but the reader should note that ground-mounted systems in Massachusetts very rarely go over 6 MW, which is half the size of the 12 MW that triggers a sound analysis in Ontario.

A recent study measured noise levels at set distances from the inverters and from the outer boundary of three ground-mounted PV arrays in Massachusetts with a capacity range of 1 to 3.5 MW. Close to the inverters (10 feet), sound levels varied from an average of 55 dBA to 65 dBA. Sound levels along the fenced boundary of the PV arrays were generally at background levels, though a faint inverter hum could be heard at some locations. Any sound from the PV array and equipment was inaudible and sound levels were at background levels at setback distances of 50 to 150 feet from the boundary. Project developers should consult with local planning and zoning officials to determine if local noise ordinances may be applicable. Many local noise ordinances establish absolute limits on project impact noise (such as a 40 dBA nighttime limit). In these communities, a noise impact assessment may be required.

Resources:

NEMA Standards Publication No. TR=1-1993(R2000), *Transformers, Regulators and Reactors*

Noise Assessment: Borrego 1 Solar Project, MUP 3300-10-26 Prepared by Ldn Consulting, Inc, Fallbrook, CA. January 14, 2011

Ontario Regulation 359/09 Renewable Energy Approval (REA) Regulation, Ontario Ministry of the Environment, Canada http://www.ontario.ca/environment-and-energy/renewable-energy-approvals

Tech Environmental, Study of Acoustic and EMF levels from Solar Photovoltaic Projects, Prepared for the Massachusetts Clean Energy Center, December 2012, http://images.masscec.com/uploads/attachments/Create%20Basic%20page/Study_of_Acoustic_and_EMF_Levels_from_Solar_Photovoltaic_Projects.pdf

Water-Related Impacts

Question: Can chemicals that might be contained in solar PV threaten public drinking water systems? Will flooding occur in cases where trees must be removed in order to install the solar arrays? How do we ensure that wetland resources are protected?

Bottom Line: Rules are in place to ensure that ground-mounted solar arrays are installed in a ways that protect public water supplies, wetlands, and other water resource areas. All solar panels are contained in a solid matrix, are insoluble and are enclosed. Therefore, releases are not a concern.

More Information: Because trees offer multiple water management, cooling and climate benefits, clear-cutting of trees for the installation of ground-mounted solar PV is discouraged. For projects that do propose to alter trees, the Massachusetts Environmental Policy Act (MEPA) has thresholds for the proposed alteration of a certain number of acres of land, the size of electrical facilities, and other criteria that trigger state review of proposed projects. Clear cutting of trees and other aspects of proposed projects would be reviewed through an Environmental Notification Form/Environmental Impact Statement if thresholds are triggered. More information is available at:

MassDEP has determined that the installation of solar arrays can be compatible with the operation and protection of public drinking water systems. This includes the installation of solar arrays within the Zone I, which is a 400-foot protective radius around a public ground water well. Solar projects proposed on lands owned by public water systems outside the Zone I may be approved subject to standard best management practices, such as the proper labeling, storage, use, and disposal of products. MassDEP has a guidance/review process in place to ensure that the installation of ground-mounted solar PV in these areas protects public water supplies.

Installing solar arrays on undeveloped land can preserve the permeable nature of the land surface provided the project design minimizes disturbance to natural vegetative cover, avoids concentrated runoff, and precipitation is otherwise recharged into the ground to the greatest extent practicable. Storm water flow, as well as information about site-specific soils and slope, is taken into account during the design and installation of solar arrays.

MassDEP discourages installation of ground-mounted solar PV systems in wetland areas, including riverfront locations. Solar projects within wetland areas are unlikely to comply with the performance standards in the Wetlands Protection Act regulations. If a solar installation is proposed in a wetland, a riverfront area, a floodplain, or within 100 feet of certain wetlands, the project proponent must file a notice of intent (or application to work in wetland areas) with the local Conservation Commission, which administers the Wetlands Protection Act at the municipal level. Copies should also go to MassDEP. Solar installations may be sited near, but outside of wetlands, in a manner that protects the functions of wetlands and that minimizes impacts from associated activities such as access and maintenance. Ancillary structures related to construction of a solar installation or transmission of power may be permitted to cross rivers and streams using best design and management practices.

Resources:

More information about the Wetlands Protection Act requirements may be found in the implementing regulations at 310 CMR 10.00: http://www.mass.gov/eea/agencies/massdep/water/regulations/310-cmr-10-00-wetlands-protection-act-regulations.html

MassDEP Guidance for Siting Wind and Solar in Public Water Supply Land: http://www.mass.gov/eea/agencies/massdep/water/regulations/wind-and-solar-energy-project-on-public-water-supply-land.html

MassDEP Chapter 91 Guidance for Renewable Energy Projects: http://www.mass.gov/eea/agencies/massdep/water/reports/chapter-91-licensing-and-renewable-energy.html

Glare

Question: How important is reflectivity and potential visual impacts from solar projects, especially near airports?

Bottom Line: Solar panels are designed to reflect only about 2 percent of incoming light, so issues with glare from PV panels are rare. Pre-construction modeling can ensure that the placement of solar panels prevents glare.

More Information: Solar panels are designed to absorb solar energy and convert it into electricity. Most are designed with anti-reflective glass front surfaces to capture and retain as much of the solar spectrum as possible. Solar module glass has less reflectivity than water or window glass. Typical panels are designed to reflect only about 2 percent of incoming sunlight. Reflected light from solar panels will have a significantly lower intensity than glare from direct sunlight.

An analysis of a proposed 25-degree fixed-tilt flat-plate polycrystalline PV system located outside of Las Vegas, Nevada showed that the potential for hazardous glare from flat-plate PV systems is similar to that of smooth water and not expected to be a hazard to air navigation.

Many projects throughout the US and the world have been installed near airports with no impact on flight operations. United Kingdom and U.S. aircraft accident databases contain no cases of accidents in which glare caused by a solar energy facility was cited as a factor.

When siting solar PV arrays pre-construction modeling can ensure the panels are placed in a way that minimizes any potential glare to surrounding areas.

Resources:

Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration, November 2010 (currently under review), http://www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide.pdf

A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems, Black & Veatch Corporation, August 2011, http://www.isrn.com/journals/re/2011/651857/

Solar Photovoltaic Energy Facilities, Assessment of Potential Impact on Aviation, Spaven Consulting, January 2011: http://www.solarchoice.net.au/blog/solar-panels-near-airports-glare-issue/

Endangered Species and Natural Heritage

Question: Who ensures that rare animal and plant species and their habitats are not displaced or destroyed during the construction of ground-mounted solar PV?

Bottom Line: Rules are in place to ensure that the installation of ground-mounted solar arrays protects state-listed rare species and animals and plants. Project proponents can check with the local Conservation Commission to determine if the footprint of the solar PV project lies within a rare species habtat.

More Information: The Massachusetts Natural Heritage and Endangered Species Program (NEHSP) was created under the Massachusetts Endangered Species Act (MESA) and is responsible for protecting rare animal and plant species and their habitats from being displaced or destroyed. Specifically, NEHSP reviews projects proposed for:

- **Priority Habitats:** These are areas known to be populated by state-listed rare species of animals or plants. Any project that could result in the alteration of more than two acres of Priority Habitat is subject to NHESP regulatory review. Projects will need to file a MESA Information Request Form, along with a project plan, a U.S. Geological Survey (USGS) topographical map of the site, and a $50 processing fee. NHESP will let project administrators know within 30 days if the filing is complete, then will determine within the next 60 days whether the project, as proposed, would result in a "take" of state-listed rare species that might require the project to redesign, scale down, or abandon its plan.
- **Estimated Habitats:** These are a sub-set of Priority Habitats that are based on the geographical range of state-listed rare wildlife – particularly animals that live in and around wetlands. If the project is proposed for one of these areas and the local Conservation Commission requires filing a Notice of Intent (NOI) under the Wetlands Protection Act, the project will need to submit copies of the NOI, project plans and a U.S. Geological Survey (USGS) topographical map to NHESP. Within 30 days of receiving this information, NHESP will send its comments to the Conservation Commission, with copies to the project administrator, project consultants, and the Department of Environmental Protection (MassDEP).

Resources:

To learn more about the NHESP review process and download a MESA Information Request Form, visit: http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/regulatory-review/mass-endangered-species-act-mesa/

For list of rare animal and plant species in Massachusetts, visit: http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html

DOER
Massachusetts Department of Energy Resources

MassDEP

MASSACHUSETTS CLEAN ENERGY CENTER