April 13, 2020

Ms. Lindsay McGovern, Vice President
Revity Energy, LLC
117 Metro Center Boulevard, Suite 1007
Warwick, RI 02886
Sent via email to: Lindsay@RevityEnergy.com

RE: Solar Panel Material of Construction Evaluation
A Proposed Solar Farm Development
Frontier Road (AP: 7, Lots: 62, 62A and 63)
Hopkinton, Rhode Island
SAGE Project No. M896

Dear Ms. McGovern:

This correspondence presents the findings of an evaluation of the material of construction for the solar panels being used for the solar project located on Frontier Road (Assessor's Plat 7 Lots 62, 62A and 63) Hopkinton, Rhode Island.

The solar project is utilizing a crystalline silicon panel manufactured by Q CELLS, referred to as Q.PEAK DUO XL-G9.3. Q.PEAK DUO XL-G9.3 is a gapless solar module that is developed for greater power output and efficiency, meaning that less panels are necessary to achieve the same amount of power generation as older solar panels. Note that Q.PEAK DUO XL-G9.3 is a new solar panel to the market and will not be available for installation until mid-2020. These panels are extreme weather rated, they have a high-tech aluminum alloy frame and are certified for high snow loads (5400 Pa) and wind loads (4000 Pa). **Attachment 1** provides the technical specification for Q.PEAK DUO XL-G9.3, note that this solar development project plans to install the 460W power class modules.

Since Q.PEAK DUO XL-G9.3 is a new product Safety Data Sheet (SDS) and toxicity data is not available for this specific module. However, Q CELLS provided data for a comparable module. **Attachment 2** provides the SDS for the comparable module, the Q.PEAK DUO series modules. Per communication with Q CELLS, this module uses the same components as what is used on Q.PEAK DUO XL-G9.3 modules. The only difference between these two modules is the gap between the cells, the Q.PEAK DUO XL-G9.3 module is gapless and allows more cells to be added compared to similar size modules. **Attachment 3** provides a copy of email communication with Q CELLS describing these details. **Table 1** provides a listing of materials that are contained in the Q.PEAK DUO series modules (i.e. comparable modules to Q.PEAK DUO XL-G9.3).

Table 1
Materials Contained in Q CELLS Solar Panel

Component	Material	Composition Range
Frame	Aluminum	8%-16%
	Silicone	<2%
Laminate	Glass	60%-80%
	Plastics (EVA, PET, PE, PPE, PC)	8%-16%
	Silicon	2%-4%
	Metals (Aluminum, Copper, Tin)	1%-3%
	Lead	<0.%
	Silver	<0.05%

Toxicity data provided by Q CELLS was Toxicity Characteristic Leaching Procedure (TCLP) analytical data, this is provided in **Attachment 4**. TCLP is a chemical analysis process that the Environmental Protection Agency (EPA) and Rhode Island Department of Environmental Management (RIDEM) use to determine if waste is considered hazardous. The thresholds that define if waste material is hazardous is defined in 40 CFR Part 261 Subpart C. If a waste constituent is below the TCLP threshold, then health effects are not expected to occur based on drinking water maximum contaminant level (MCL) standards. TCLP leach test is for assessing long-term contaminant release potential for landfills

TCLP data is not available for Q.PEAK DUO XL-G9.3 but is available for a comparable module (Q.PEAK DUO L-G5.2). **Table 2** provides a summary of TCLP analytical data for this comparable module; as displayed all analyzed constituents are below EPA/RIDEM's threshold for hazardous waste. Meaning that health effects are not expected to occur. Per communication with Q CELLS (**Attachment 3**), there is the potential for a 10% increase in materials in the Q.PEAK DUO XL-G9.3 compared to the Q.PEAK DUO L-G5.2. However, this is not expected to cause any TCLP exceedances as amounts would have to increase over 300% to cause any exceedances of EPA/RIDEM's threshold for hazardous waste.

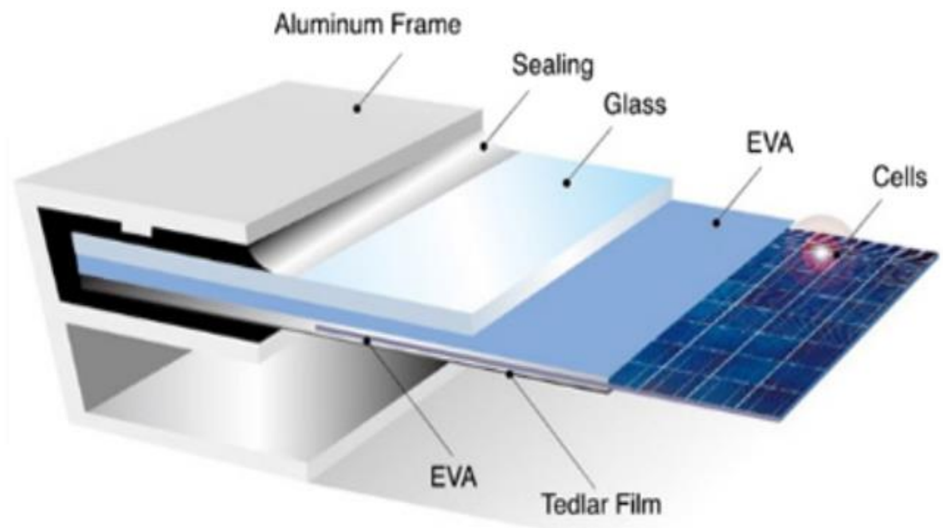
Table 2
Summary of TCLP Analytical Data

Contaminant	Greatest TCLP Concentration Reported	RCRA TCLP Threshold	Hazardous Waste Determination
Mercury (mg/L)	< 0.0001	0.2	Not Hazardous Waste
Arsenic (mg/L)	< 0.01	5	Not Hazardous Waste
Barium (mg/L)	0.12	100	Not Hazardous Waste
Cadmium (mg/L)	< 0.01	1	Not Hazardous Waste
Chromium (mg/L)	< 0.01	5	Not Hazardous Waste
Lead (mg/L)	1.48	5	Not Hazardous Waste
Selenium (mg/L)	< 0.01	1	Not Hazardous Waste
Silver (mg/L)	< 0.01	5	Not Hazardous Waste

Comparing TCLP results to determine if there may be environmental impacts related to solar panel operation is highly conservative. During the TCLP test, waste samples are crushed to a particle size less than 9.5 mm. The crushed material is then mixed with an acid to determine how much of a toxic component in the crushed material would leach out. Note that the smaller the particle size the greater potential for the material to leach, as it provides a greater surface area. TCLP process is a regulated analytical procedure and is defined in EPA Method 1311 Toxicity Characteristic Leaching Procedure. The objective of TCLP is to assess the risk to ground water when potentially hazardous waste is co-disposed with garbage in sanitary landfills, it simulates worst case management of hazardous waste in a landfill. TCLP leach test is for assessing long-term contaminant release potential. This is not a direct comparison to the actual site conditions, as TCLP is more conservative. TCLP is a worst-case scenario, as at no time during normal operation or if a panel was to break would it be exposed to soil/groundwater at the small particle sizes that were analyzed via TCLP.

Crystalline silicon solar panels, such as Q.PEAK DUO XL-G9.3, are manufactured such that all components are fully encased in glass. **Figure 1** provides a schematic showing the different "layers" to a solar panel. Scenarios for how metal components listed in the panel SDS would impact groundwater are unlikely. The metal components are located in the area referred to as "cells" in **Figure 1**. These metals are in the solid form and require a leaching mechanism to get the heavy metal from the panel cell to the soil. Rainwater would be required to enter a broken panel and then travel from the panel cell to the soil, and then partition from the soil to groundwater. The contaminant evaluated for potential leaching in the Q.PEAK DUO XL-G9.3 is lead, as all other contaminants are non-detect or significantly lower than the hazardous threshold. However, environmental contamination due to lead in Q.PEAK DUO XL-G9.3 panels is not a concern because there is not a significant amount of lead found in the panels.

Figure 1
Solar Panel Schematic



From: N.C. Clean Energy Technology Center. "Health and Safety Impacts of Solar Photovoltaics." May 2017.

The lead amount in the Q.PEAK DUO XL-G9.3 is less than 0.1%. Under normal conditions lead does not react with water. In order for lead to leach into water the lead must come into contact with moist air. A layer of lead oxide (PbO) forms at the surface of the metal, when both oxygen and water are present metallic lead is converted to lead hydroxide (Pb(OH)2) [2Pb(s)+ O2(g) + 2H2O(l) -> 2 Pb(OH)2(s)]. This lead hydroxide is what would then potentially leach into water during rain events. This process is not expected to generate hazardous conditions due to the low amount of lead in the Q.PEAK DUO XL-G9.3 panels.

Note that this solar development is equipped with an automated system that would detect any voltage drop that would indicate that there was a significant break to the panel. If a panel was to break allowing for moist air to come into contact with lead, the solar development maintenance staff would be alerted and the panel would be repaired or replaced in a timely and comprehensive manner. Thus, further reducing the potential for any amount of lead reaching the soil or groundwater.

In 2017 the N.C. Clean Energy Technology Center assessed the health and safety impacts of solar photovoltaics, a copy of this assessment is provided in **Attachment 5**. This assessment evaluated hazardous materials found in solar photovoltaic development. The findings of this assessment regarding lead is such that "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". The assessment also compares the quantity of lead in solar panels to other common materials, demonstrating that the amount of lead in solar panels is very low. For example, "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. At 13 g/panel, each panel contains one-half of the lead in a typical 12-gauge shotgun shell." The assessment also specially addresses crystalline silicon panels, which "concludes that they do not pose a material risk of toxicity to public health and safety". Note that the N.C. Clean Energy Technology Center assessment is not specifically addressing the Q.PEAK DUO XL-G9.3 panel, it is a general evaluation of solar panels.

In May 2019, the Journal of Natural Resources and Development published a paper titled "Potential for leaching of heavy metals and metalloids from crystalline silicon photovoltaic systems" authored by Seth A. Robinson (Department of Biology, University of Florida) and George A. Meindl (Environmental Studies Program, Binghamton University); a copy of this paper is provided in **Attachment 6**. This paper evaluated a solar farm in located in Buffalo, New York to determine if soil directly beneath solar panels and adjacent fields were contaminated by metals (lead, cadmium, lithium, strontium, nickel, barium, zinc, and copper) and metalloids (selenium) found in the panels. The study concluded that no elements exceeded soil screening thresholds established by the EPA's Ecological Soil Screening Level (Eco-SSL). The authors of the paper do note that this assessment is specific to the panels evaluated, however it is a case example of field data demonstrating no environmental impacts from components found in solar panels.

In conclusion, the data provided for the Q.PEAK DUO XL-G9.3 demonstrates that the panels are not expected to cause environmental contamination to soils or groundwater. These panels have very small amounts of metal, and even if these panels were broken into very small pieces (which would require an external force of significant magnitude, such as a mechanical shredder) the amount of contaminants that has the potential to leach to the environment is below EPA/RIDEM's threshold for hazardous waste; meaning that health effects are not expected to occur. One should note that the TCLP is a conservative comparison as it does not represent normal panel operation or how a broken panel would impact soil/groundwater, as TCLP evaluates the components as small particles sizes exposed to leaching liquid. TCLP leach test is for assessing long-term contaminant release potential for landfills. However, since the material is not considered hazardous based on those standards, normal panel operation or exposure from a broken panel would not present environmental concern.

Should you have any questions or concerns, please do not hesitate to contact us.

Sincerely,
SAGE Environmental, Inc.

John Clark

John Clark
Senior Chemical Engineer

Nicole Mulanaphy

Nicole Mulanaphy, P.E.
Senior Project Manager

Attachments:

Attachment 1: Q.PEAK DUO XL-G9.3 technical data sheet
Attachment 2: Q CELLS Solar Panel SDS
Attachment 3: Q CELLS E-mail Describing SDS and Toxicity Data
Attachment 4: TCLP Analytical Data
Attachment 5: N.C. Clean Energy Technology Center Paper
Attachment 6: Journal of Natural Resources and Development Article

Attachment 1: Q.PEAK DUO XL-G9.3 technical data sheet

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powered by Q.ANTUM DUO

DRAFT

Q.PEAK DUO XL-G9.3
440-460

ENDURING HIGH PERFORMANCE

pv magazine award 2017 top innovation

Photon — Q.PRO-G2 235 Best polycrystalline solar module 2014 — Q CELLS — 174 modules tested

EUPD RESEARCH — TOP BRAND PV — MODULES — EUROPE — 2019

Q CELLS YIELD SECURITY
- ANTI PID TECHNOLOGY (APT)
- HOT-SPOT PROTECT (HSP)
- TRACEABLE QUALITY (TRA.Q™)
- ANTI LID TECHNOLOGY (ALT)

BREAKING THE 20% EFFICIENCY BARRIER
Q.ANTUM Technology combined with zero gap cell layout boosts module efficiency up to 20.8% absolute.

LOW ELECTRICITY GENERATION COSTS
Higher yield per surface area, lower BOS costs and up to 30 watts more power per module.

ENDURING HIGH PERFORMANCE
Long-term yield security with Anti LID Technology, Anti PID Technology[1], Hot-Spot Protect and Traceable Quality Tra.Q™.

EXTREME WEATHER RATING
High-tech aluminium alloy frame, certified for high snow (5400 Pa) and wind loads (2400 Pa).

A RELIABLE INVESTMENT
Inclusive 12-year product warranty and 25-year linear performance warranty[2].

STATE OF THE ART MODULE TECHNOLOGY
Q.ANTUM DUO combines cutting edge cell separation and innovative 12-busbar design with Q.ANTUM Technology.

[1] APT test conditions according to IEC/TS 62804-1:2015, method B (−1500 V, 168 h)
[2] See data sheet on rear for further information.

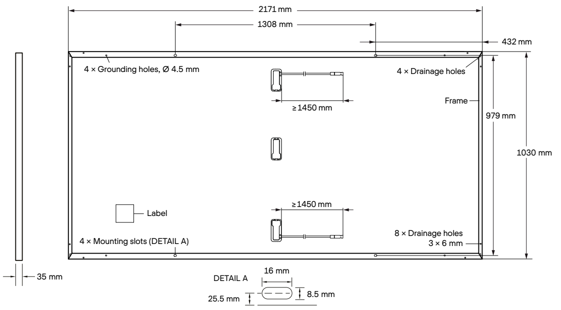
THE IDEAL SOLUTION FOR:
- Rooftop arrays on commercial / industrial buildings
- Ground-mounted solar power plants

Engineered in Germany

Q CELLS

MECHANICAL SPECIFICATION

Format	2171 mm × 1030 mm × 35 mm (including frame)
Weight	26.0 kg
Front Cover	3.2 mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Composite film
Frame	Anodised aluminium
Cell	6 × 26 monocrystalline Q.ANTUM solar half cells
Junction box	53-101 mm × 32-60 mm × 15-18 mm Protection class IP67, with bypass diodes
Cable	4 mm² Solar cable; (+) ≥1450 mm, (–) ≥1450 mm
Connector	Stäubli MC4-Evo2, Hanwha Q CELLS HQC4, Amphenol UTX, Renhe 05-8, JMTHY JM601A, Tongling Cable01S-F; IP68 or Friends PV2e; IP67

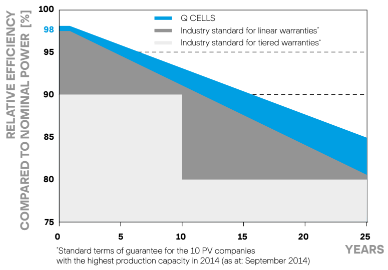


ELECTRICAL CHARACTERISTICS

POWER CLASS				440	445	450	455	460
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W)								
Minimum	Power at MPP[1]	P_{MPP}	[W]	440	445	450	455	460
	Short Circuit Current[1]	I_{SC}	[A]	10.55	10.57	10.60	10.62	10.65
	Open Circuit Voltage[1]	V_{OC}	[V]	53.13	53.17	53.20	53.24	53.27
	Current at MPP	I_{MPP}	[A]	10.02	10.07	10.12	10.16	10.21
	Voltage at MPP	V_{MPP}	[V]	43.92	44.21	44.49	44.76	45.04
	Efficiency[1]	η	[%]	≥19.7	≥19.9	≥20.1	≥20.3	≥20.6
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]								
Minimum	Power at MPP	P_{MPP}	[W]	329.5	333.2	337.0	340.7	344.5
	Short Circuit Current	I_{SC}	[A]	8.50	8.52	8.54	8.56	8.58
	Open Circuit Voltage	V_{OC}	[V]	50.10	50.13	50.17	50.20	50.24
	Current at MPP	I_{MPP}	[A]	7.88	7.92	7.97	8.01	8.05
	Voltage at MPP	V_{MPP}	[V]	41.81	42.06	42.30	42.53	42.77

[1]Measurement tolerances P_{MPP} ±3%; I_{SC}; V_{OC} ±5% at STC: 1000 W/m², 25±2 °C, AM 1.5 according to IEC 60904-3 • [2]800 W/m², NMOT, spectrum AM 1.5

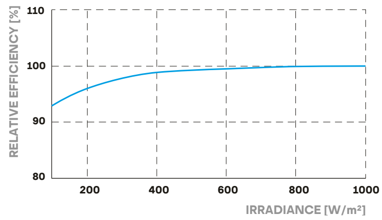
Q CELLS PERFORMANCE WARRANTY



At least 98% of nominal power during first year. Thereafter max. 0.54% degradation per year. At least 93.1% of nominal power up to 10 years. At least 85% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[% / K]	+0.04	Temperature Coefficient of V_{OC}	β	[% / K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[% / K]	−0.35	Normal Module Operating Temperature	NMOT	[°C]	43±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1500 (IEC) / 1500 (UL)	Safety Class	II
Maximum Reverse Current	I_R	[A]	20	Fire Rating based on ANSI / UL 1703	C / TYPE 1
Max. Design Load, Push / Pull		[Pa]	3600 / 1600	Permitted Module Temperature on Continuous Duty	−40 °C - +85 °C
Max. Test Load, Push / Pull		[Pa]	5400 / 2400		

QUALIFICATIONS AND CERTIFICATES

IEC 61215:2016; IEC 61730:2016, Application Class II;
This data sheet complies with DIN EN 50380.

C Certified UL 1703 (254141) US

PACKAGING INFORMATION

Number of Modules per Pallet	29
Number of Pallets per Trailer (24 t)	24
Number of Pallets per 40' HC-Container (26 t)	20
Pallet Dimensions (L × W × H)	2241 × 1150 × 1220 mm
Pallet Weight	814 kg

Note: Installation instructions must be followed. See the installation and operating manual or contact our technical service department for further information on approved installation and use of this product.

Hanwha Q CELLS GmbH
Sonnenallee 17-21, 06766 Bitterfeld-Wolfen, Germany | **TEL** +49 (0)3494 66 99-23444 | **FAX** +49 (0)3494 66 99-23000 | **EMAIL** sales@q-cells.com | **WEB** www.q-cells.com

Engineered in Germany

Attachment 2: Q CELLS Solar Panel SDS

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PRODUCT SAFETY DATA SHEET

HANWHA Q CELLS SOLAR PV MODULES ARE ARTICLES AS DEFINED BY THE OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION HAZARD COMMUNICATION STANDARD (HCS), 29 C.F.R. § 1910.1200 AND ARE EXEMPT FROM THE LABELING AND SAFETY DATA SHEETS (SDS) REQUIREMENTS OF THE STANDARD.

Hanwha Q CELLS provides this product safety data sheet only for convenience of interested parties in the United States of America who are used to the format of safety data sheets in order to assess the product safety. This product safety data sheet does not replace any other documents provided by Hanwha Q CELLS such as Safety Information, Installation and Operation Manual, Packaging and Transport Information, Product Data Sheet as well as Warranty Terms of the respective product.

SECTION 1: IDENTIFICATION

Solar PV modules convert light into electricity. Light-sensitive cells are electrically interconnected in series and sealed between glass and plastic foils for this purpose. This product safety data sheet is applicable to the following solar PV modules of the Q CELLS brand made by Hanwha Q CELLS:

- Q.PLUS-G4.X, Q.PLUS BFR-G4.X, Q.PLUS L-G4.X, Q.PEAK-G4.X, Q.PEAK BLK-G4.X, Q.PEAK L-G4.X,
- Q.PLUS DUO-G5, Q.PLUS DUO BLK-G5, Q.PLUS DUO L-G5, Q.PLUS DUO-G5.X, Q.PLUS DUO BLK-G5.X, Q.PLUS DUO L-G5.X,
- Q.PEAK DUO-G5, Q.PEAK DUO BLK-G5, Q.PEAK DUO L-G5, Q.PEAK DUO-G5.X, Q.PEAK DUO BLK-G5.X, Q.PEAK DUO L-G5.X,
- Q.PEAK DUO-G6, Q.PEAK DUO BLK-G6, Q.PEAK DUO L-G6, Q.PEAK DUO-G6.X, Q.PEAK DUO BLK-G6.X, Q.PEAK DUO L-G6.X

Minor variations within the product families listed above can be identified by a versioning system which replaces character “X” with numerals of either “1”, “2” or “3” to form G4.1, G4.2, G4.3, G5.1, G5.2, G5.3, G6.1, G6.2 and G6.3, respectively. All of these variants as well as the ones with additional suffix “/TAA” are covered by this product safety data sheet. This is also true for B-grade modules which have minor optical imperfections. Product names of these replace “Q.” with “B.LINE”. B-grade modules of Q.PEAK-G4.1 are named B.LINE PEAK-G4.1 for example.

Responsible Party as Importer:
Name: Hanwha Q CELLS America
Address: 300 Spectrum Center Drive, Suite 1250, Irvine, CA 92618
Phone: 1-949-748-5996

SECTION 2: IDENTIFICATION OF SAFETY RISKS (HAZARDS IDENTIFICATION)

Hanwha Q CELLS solar PV modules do not pose any risk of hazardous chemicals. Hazard symbols and precautionary hazard statements for hazardous chemicals are not applicable. No symptoms or effects – neither acute nor delayed – have to be expected when Hanwha Q CELLS solar PV modules are handled as stipulated in the Installation and Operation Manual. Hanwha Q CELLS provides a Safety Information sheet with all modules shipments. This document contains detailed risk statements and recommendations for installation and operation. Before installing the module, read the Installation and Operation Manual for Q CELLS modules carefully. You can obtain the complete Installation and Operation Manual from your retailer.

Attention: Only qualified and authorized specialists may install modules and put them into operation. Keep children and unauthorized persons away from the modules.

Risks:
- Risk of death from electrocution! Solar modules generate electricity and are energized as soon as they are exposed to light.
- In rare cases, solar PV modules – as any other electrical device – can cause fire due to worn electrical contacts which result in electrical arching.
- Solar PV modules can reach high temperatures which can cause skin burns.
- Sharp edges, corners and broken glass can cause injuries.
- Solar PV modules can cause Injuries due to their weight.
  - Falling solar PV modules can cause injuries.
  - Lifting solar PV modules can cause injuries.

For precautionary statements, please refer to the Installation and Operations Manual of the respective product.

MISUSE OR INCORRECT USE OF SOLAR MODULES VOIDS THE LIMITED WARRANTY AND MAY CREATE A SAFETY HAZARD AND RISK PROPERTY DAMAGE. THIS INCLUDES IMPROPER INSTALLATION OR CONFIGURATION, IMPROPER MAINTENANCE, UNINTENDED USE, AND UNAUTHORIZED MODIFICATION.

PRODUCT SAFETY DATA SHEET

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

Safety data sheets are only required for hazardous chemicals covered by the Hazard Communication Standard (HCS). Solar PV modules made by Hanwha Q CELLS are not covered by HCS. The following table provides an overview of materials solar PV modules by Hanwha Q CELLS are made of. The values given for the share of weight are targets and can vary for the products covered by this Product Safety Data Sheet.

COMPONENT	MATERIAL	TOTAL SHARE	REMARK
FRAME	Aluminum	8% – 16%	not hazardous
	Silicone	<2%	not hazardous, see section 8
LAMINATE	Glass	60% – 80%	not hazardous
	Plastics (EVA, PET, PE, PPE, PC)	8% – 16%	no hazards known
	Silicon	2% – 4%	not hazardous
	Metals (Aluminum, Copper, Tin)	1% – 3%	not hazardous
	Lead	<0,1%	hazardous
	Silver	<0,05%	not hazardous

SECTION 4: FIRST-AID MEASURES

In case of electrocution:

- Always protect yourself by taking all necessary safety precautions before rescuing persons injured.
- Attention: Stay away from sources of high voltage and leave the rescue to qualified personnel with appropriate personal protection equipment!
- Call emergency rescue services.
- Do not touch live parts. Qualified personnel should shut down the PV system as far as possible – e.g. disconnect the modules at the inverter before uncovering any live electrical parts. Be sure to observe the specified time intervals after switching off the inverter. Highvoltage components need time to discharge. Follow OSHA requirements for control of hazardous energy at 29 C.F.R. § 1910.147.
- In the event a person is electrocuted or affected by electrical energy of the solar PV module, CALL 911. Before attempting rescue, SHUTDOWN THE POWER SOURCE.
- Remove the victim from the power source using only insulated tools ONLY IF CONTACT WITH LIVE ELECTRICAL COMPONENTS CAN B PREVENTED.
- Carefully move the injured from the zone of danger.
- After moving to a safe location, check heartbeat, respiration and consciousness of the injured person.
- Apply appropriate life-saving measures (CPR) accordingly before taking care of minor injuries.
- Consult a medical professional even if there are no visible injuries.
  - Flush thermal skin burns caused by touching hot surfaces of solar PV modules with cool water. Consult a medical professional.
  - Injuries due to sharp edges, corners and broken glass need to be appropriately treated. Consult a medical professional.
  - Other types of injuries need to be treated appropriately as well. Consult a medical professional.

SECTION 5: FIRE-FIGHTING MEASURES

- Hanwha Q CELLS solar PV modules are fire rated as Class C according to IEC and UL 1703 as well as Type 1 according to UL 1703.
- Hanwha Q CELLS solar PV modules are extensively tested at the factory to ensure electrical safety of the product before shipment.
- In rare cases, solar PV modules – as any other electrical device – can cause fire due to worn electrical contacts which result in electrical arching.
- In case solar PV modules which are not part of an array are on fire, USE FIRE EXTINGUISHERS RATED FOR ELECTRICAL EQUIPMENT, Class C.
- IN CASE A SOLAR PV MODULE ARRAY IS PRESENT, ANY FIRE SHOULD ONLY BE FOUGHT BY PROFESSIONAL FIREFIGHTERS. FIREFIGHTERS NEED TO TAKE PRECAUTIONS FOR ELECTRICAL VOLTAGES UP TO 1,500 VOLTS (DC).
- Some components of the modules can burn. Potential combustion products include oxides of carbon, nitrogen and silicon.
- In case of prolonged fire, solar PV modules may lose their structural integrity.

General recommendations from the below-mentioned reports:

- Fire service personnel should follow their normal tactics and strategies at structure fires involving solar power systems, but do so with awareness and understanding of exposure to energized electrical equipment. Emergency response personnel should operate normally, and approach this subject area with awareness, caution, and understanding to assure that conditions are maintained as safely as possible.
- Care must be exercised during all operations, both interior and exterior.
- Responding personnel must stay back from the roofline in the event modules or sections of an array may slide off the roof.
- Contacting a local professional PV installation company should be considered to mitigate potential hazards.
- Turning off an array is not as simple as opening a disconnect switch. As long as the array is illuminated, parts of the system will remain energized.
- When illuminated by artificial light sources such as fire department light trucks or an exposure fire, PV systems are capable of producing electrical power sufficient to cause inability to let go from electricity as a result of stimulation of muscle tissue, also known as lock-on hazard.
- Firefighting foam should not be relied upon to block light.
- The electric shock hazard due to application of water is dependent on voltage, water conductivity, distance and spray pattern.
- It is recommendable to fight fire with water instead of foam if a PV system is present. Salt water should not be used.
- Firefighter's gloves and boots afford limited protection against electrical shock provided the insulating surface is intact and dry. They should not be considered equivalent to electrical personal protection equipment.

Readers interested in more details may refer to the following reports:

- National Fire Protection Association, Fire Protection Research Foundation report "Fire Fighter Safety and Emergency Response for Solar Power Systems" issued May 2010, revised October 2013
- Important recommendations from a report called "Firefighter Safety and Photovoltaic Installations Research Project" issued by Underwriters Laboratories on November 29, 2011

SECTION 6: FIRE-FIGHTING MEASURES

This section is not applicable.

SECTION 7: HANDLING AND STORAGE

Before installing the module, read the Installation and Operation Manual for Q CELLS modules carefully. Noncompliance with the instructions may result in damage and physical injury or death. Only qualified and authorized specialists may install modules and put them into operation. You can obtain the complete installation manual from your retailer.

Details about transport and storage of palletized Hanwha Q CELLS solar PV modules can be found in the Packaging and Transport Information of the respective module type.

Storage, transport and unpacking:

- Store the module dry, well-ventilated and properly secured. The original packaging is not weatherproof.
- Always transport the module in its original packaging.
- Do not stack the modules. This prevents damage of the junction box.
- The module is made of glass. Take great care when unpacking, storing and transporting it.
- Do not subject the module glass to any mechanical stress (e.g. through torsion or deflection). Do not step on the module or place any objects onto the module.
- Protect both sides of the module against scratching and other damage.
- Carry the module by holding the edges with both hands, or use a glass suction lifter.
- Never lift or carry the module using the module junction box or wiring. Avoid pulling on the wiring at all costs.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Before installing the module, read the Installation and Operation Manual carefully. Noncompliance with the instructions may result in damage and physical injury. Only qualified and authorized specialists may install modules and put them into operation. You can obtain the complete installation manual from your retailer.

- Please follow the valid national regulations and safety guidelines for the installation of electrical devices and systems.
- Please make sure to take all necessary safety precautions.
- Ensure that all personnel are aware of and adhere to accident-prevention and safety regulations.
- For handling of modules wear suitable protective gloves.
- Do not install damaged modules. Ensure that all electrical components are in a proper, dry, and safe condition.
- Do not modify the module (e.g. do not drill any additional holes). Never open the junction box.
- Ensure that modules and tools are not subject to moisture or rain at any time during installation. Only use dry, insulated tools for electrical work.
- Only connect cables with plugs. Ensure for a tight connection between the plugs. Plugs click together audibly.
- Cover the modules with an opaque material during installation. Cover the modules to be disconnected.

Silicones used in manufacturing release methanol during curing. Once cured, no additional methanol is released during use. Small amounts of these chemicals may be present in shipping cartons. Upon receipt, open container in a well ventilated location and allow to stand for 5 minutes before removing units from cartons. Exposures above recommended limits for methanol of 200 ppm eight-hour time-weighted-average (TWA) will not occur.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

- Physical state: solid
- Voltage: refer to data sheet (below 50 volts for a single module)

Attention: Voltage of single modules add up when modules are electrically connected in series. Hanwha Q CELLS solar PV modules are designed and certified for voltages up to 1,000 volts or even up to 1,500 volts. Connection of modules in series is only permitted up to the maximum system voltage as listed in the applicable data sheet.

- Weight: refer to data sheet
- Solubility in water: insoluble in water

SECTION 10: STABILITY AND REACTIVITY

Under normal operating conditions as specified in the Product Data Sheet, Hanwha Q CELLS solar PV modules are chemically stable.

- Hanwha Q CELLS solar PV modules are tested for salt spray and ammonia resistance according to IEC 61701 and IEC 62716, respectively.
- Hanwha Q CELLS solar PV modules support ambient operating temperatures from –40 °C to +85 °C (–40 °F to +185 °F).
- Do not install modules above 13.120 ft (4000 m) altitude above sea level.
- Some components of the modules can burn. Potential combustion products include oxides of carbon, nitrogen and silicon.
- Do not scratch off dirt. Use a soft cellulose cloth or sponge to carefully wipe off stubborn dirt. Do not use micro fleece wool or cotton cloths.
- Rinse dirt off with lukewarm water (dust, leaves, etc.)
- Use an alcohol based glass cleaner. Do not use abrasive detergents or tensides.
- Isopropyl alcohol (IPA) can be used selectively to remove stubborn dirt and stains within one hour after it appeared.
- Follow the safety guidelines provided by the IPA manufacturer.
- Do not let IPA run down between the module and the frame or into the module edges.

PRODUCT SAFETY DATA SHEET

SECTION 11: TOXICOLOGICAL INFORMATION

Small amounts of methanol may be present inside shipping cartons. Open cartons and allow to vent before removing units. No exposure to hazardous chemicals will occur when the units are in use.

SECTION 12: ECOLOGICAL INFORMATION

Hanwha Q CELLS solar PV modules are designed to withstand outdoor operating conditions for 25 years. Biodegradation is not expected due to high chemical stability of the components.

SECTION 13: DISPOSAL CONSIDERATIONS

Hanwha Q CELLS solar PV modules should be recycled rather than dumped in a landfill. Raw materials of the product can be recovered by recycling companies. Disposal must be in accordance with national and local laws and regulations for electric/electronic waste.

SECTION 14: TRANSPORT INFORMATION

Hanwha Q CELLS solar PV modules can be shipped via standardized container freight. Regulations for hazardous goods do not apply. For further details, please refer to the Packaging and Transport Information which can be provided as a separate document by Hanwha Q CELLS.

SECTION 15: REGULATORY INFORMATION

- Hanwha Q CELLS solar PV modules are tested according to international standards IEC 61215, IEC 61730 as well as US standards UL 1703.
- Please refer to the Installation and Operation Manual and Product Data Sheet of the respective Hanwha Q CELLS solar PV module.

SECTION 16: OTHER INFORMATION

- Date of initial creation of this product safety data sheet: July 1, 2016
- Date of last revision: August 14, 2018

Hanwha Q CELLS America Inc.
300 Spectrum Center Drive, Suite 1250, Irvine, CA 92618, USA | **TEL** +1 949 748 59 96 | **EMAIL** inquiry@us.q-cells.com | **WEB** www.q-cells.us

Attachment 3: Q CELLS E-mail Describing SDS and Toxicity Data

(the rest of this page is intentionally blank)

SAGE ENVIRONMENTAL

Nicole Mulanaphy <nmulanaphy@sage-enviro.com>

TCLP Report and SDS for Q.PEAK DUO XL-G9.3 modules

Ralph Alvarado <ralph.alvarado@us.q-cells.com> Wed, Apr 8, 2020 at 1:40 PM
To: Nicole Mulanaphy <nmulanaphy@sage-enviro.com>
Cc: James Matarese <jmatarese@borregosolar.com>, Wai Lo <wai.lo@us.q-cells.com>, Lindsay McGovern <lindsay@revityenergy.com>, Ryan Palumbo <ryan@revityenergy.com>, "jclark@sage-enviro.com" <jclark@sage-enviro.com>

Dear Nicole,

We have looked into the Q.PEAK DUO XL-G9.3 modules in regards TCLP. The difference between the two modules, Q.PEAK DUO L-G5.2 and Q.PEAK DUO XL-G9.3, has approximately less than 10% increase of components. XL-G9.3 modules are bigger but they use the same interconnections. There is a slight increase in lead but not enough to cross the EPA limits and other components such as glass cell, frame are also larger which in turn will give similar outcome. Our test results shown values of ~1.5mg/L so even with slight increased lead content we will still be below the limit of 5mg/L. All in all we can use the TCLP test report for Q.PEAK DUO L-G5.2 for Q.PEAK DUO XL-G9.2 modules and all of our current modules. Also power class does not have an effect on TCLP results as they are the same cells but produce more power due to flashed efficiency.

TCLP Testing Process:

100g of component samples with percentages matching full size module (Cells, frames, backsheet, j-box, connectors, cables, glass) were sent to Jones Environmental lab for TCLP testing. Modules were tested for Silver, Arsenic, Barium, Cadmium, Chromium, Selenium, Lead and Mercury. Most of these elements were not detected which is not surprising since we do not use them on our modules. The elements that were detected are under the required limits, test steps are shown on the EPA document section 7.0. The test report attached shows levels under the required limits and therefore passing and not considered toxic when disposed on landfills. In addition Q.PEAK DUO L-G5.2 and Q.PEAK DUO XL-G9.3 use the same cells, frames, j-boxes, interconnections so test applies to both (see above for details). Let me know if you have further questions.

Attached is the SDS for our current modules (Q.PEAK DUO series modules) which use same components as what is used on Q.PEAK DUO XL-G9.3 modules. The only difference is the gap between the cells, XL-G9.3 module are gapless it allows more cells to be added in similar size modules. As mentioned above, components on the XL-G9.3 modules should not have trouble passing the test (see explanation above).

Best Regards,

Ralph,

Q CELLS North America

Ralph Alvarado, EE

Product Manager | Products, Technology & Innovation

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M +1 619 438 4100

E ralph.alvarado@us.q-cells.com

W www.q-cells.us

Q CELLS provides affordable and smart energy solutions through technology and innovation to c reate a sustainable future for the planet.

Hanwha Q CELLS America Inc.
400 Spectrum Center Drive,
Suite 1400
Irvine, CA 92618

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4 attachments

TCLP Report 2019.pdf
1057K

Hanwha_Q_CELLS_Product_safety_data_sheet_2018-08_Rev04_NA.PDF
117K

TCLP Limits, EPA.pdf
113K

TCLP EPA Regulatory definitions.pdf
32K

Attachment 4: TCLP Analytical Data

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JONES ENVIRONMENTAL
LABORATORY RESULTS

Client:	Hanwha Q CELLS America Inc.	**Report date:**	4/4/2019
Client Address:	400 Spectrum Center Dr., Suite 1400 Irvine, CA 92618	**JEL Ref. No.:**	ST-13602
Attn:	Ralph Alvarado	**Date Sampled:**	4/1/2019
		Date Received:	4/1/2019
		Date Analyzed:	4/3-4/2019
		Physical State:	Solar Panel Q.PEAK DUO L-G5.2 XXX

ANALYSES REQUESTED

1. TCLP Metals by ICP-OES

Approval:

Angela Haar, Ph. D.
Mobile Lab Manager

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JONES ENVIRONMENTAL LABORATORY RESULTS

Client:	Hanwha Q CELLS America Inc.	**Report date:**	4/4/2019
Client Address:	400 Spectrum Center Dr., Suite 1400 Irvine, CA 92618	**Jones Ref. No.:**	ST-13602
Attn:	Ralph Alvarado	**Date Sampled:**	4/1/2019
		Date Received:	4/1/2019
		Date Analyzed:	4/3-4/2019
		Physical State:	Solar Panel - Q.PEAK DUO L-G5.2 XXX

Sample ID: **Sample 1** **Jones ID:** **ST-13602-01**

TCLP Metals by ICP-OES

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Analytes:							
Silver, Ag	**0.01**	1	TCLP_040219-01	4/2/2019	4/3/2019	0.01	mg/L
Arsenic, As	ND	1	"	"	"	0.01	mg/L
Barium, Ba	**0.10**	1	"	"	"	0.01	mg/L
Cadmium, Cd	ND	1	"	"	"	0.01	mg/L
Chromium, Cr	ND	1	"	"	"	0.01	mg/L
Selenium, Se	ND	1	"	"	"	0.01	mg/L
Lead, Pb	**1.48**	1	"	"	"	0.01	mg/L

EPA 7471A - Mercury by Cold Vapor Atomic Absorption

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Mercury, Hg	ND	1	TCLP_040219-01	4/2/2019	4/4/2019	0.1	µg/L

ND= Not Detected

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JONES ENVIRONMENTAL LABORATORY RESULTS

Client:	Hanwha Q CELLS America Inc.	**Report date:**	4/4/2019
Client Address:	400 Spectrum Center Dr., Suite 1400 Irvine, CA 92618	**Jones Ref. No.:**	ST-13602
Attn:	Ralph Alvarado	**Date Sampled:**	4/1/2019
		Date Received:	4/1/2019
		Date Analyzed:	4/3-4/2019
		Physical State:	Solar Panel - Q.PEAK DUO L-G5.2 XXX

Sample ID: **Sample 2** **Jones ID:** **ST-13602-02**

TCLP Metals by ICP-OES

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Analytes:							
Silver, Ag	ND	1	TCLP_040219-01	4/2/2019	4/3/2019	0.01	mg/L
Arsenic, As	ND	1	"	"	"	0.01	mg/L
Barium, Ba	**0.07**	1	"	"	"	0.01	mg/L
Cadmium, Cd	ND	1	"	"	"	0.01	mg/L
Chromium, Cr	ND	1	"	"	"	0.01	mg/L
Selenium, Se	ND	1	"	"	"	0.01	mg/L
Lead, Pb	**1.36**	1	"	"	"	0.01	mg/L

EPA 7471A - Mercury by Cold Vapor Atomic Absorption

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Mercury, Hg	ND	1	TCLP_040219-01	4/2/2019	4/4/2019	0.1	µg/L

ND= Not Detected

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JONES ENVIRONMENTAL LABORATORY RESULTS

Client:	Hanwha Q CELLS America Inc.	**Report date:**	4/4/2019
Client Address:	400 Spectrum Center Dr., Suite 1400 Irvine, CA 92618	**Jones Ref. No.:**	ST-13602
Attn:	Ralph Alvarado	**Date Sampled:**	4/1/2019
		Date Received:	4/1/2019
		Date Analyzed:	4/3-4/2019
		Physical State:	Solar Panel - Q.PEAK DUO L-G5.2 XXX

Sample ID: **Sample 3** **Jones ID:** **ST-13602-03**

TCLP Metals by ICP-OES

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Analytes:							
Silver, Ag	ND	1	TCLP_040219-01	4/2/2019	4/3/2019	0.01	mg/L
Arsenic, As	ND	1	"	"	"	0.01	mg/L
Barium, Ba	**0.12**	1	"	"	"	0.01	mg/L
Cadmium, Cd	ND	1	"	"	"	0.01	mg/L
Chromium, Cr	ND	1	"	"	"	0.01	mg/L
Selenium, Se	ND	1	"	"	"	0.01	mg/L
Lead, Pb	**1.07**	1	"	"	"	0.01	mg/L

EPA 7471A - Mercury by Cold Vapor Atomic Absorption

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Mercury, Hg	ND	1	TCLP_040219-01	4/2/2019	4/4/2019	0.1	µg/L

ND= Not Detected

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JONES ENVIRONMENTAL LABORATORY RESULTS

Client:	Hanwha Q CELLS America Inc.	**Report date:**	4/4/2019
Client Address:	400 Spectrum Center Dr., Suite 1400 Irvine, CA 92618	**Jones Ref. No.:**	ST-13602
Attn:	Ralph Alvarado	**Date Sampled:**	4/1/2019
		Date Received:	4/1/2019
		Date Analyzed:	4/3-4/2019
		Physical State:	Solar Panel - Q.PEAK DUO L-G5.2 XXX

Sample ID: **Sample 4** **Jones ID:** **ST-13602-04**

TCLP Metals by ICP-OES

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Analytes:							
Silver, Ag	ND	1	TCLP_040219-01	4/2/2019	4/3/2019	0.01	mg/L
Arsenic, As	ND	1	"	"	"	0.01	mg/L
Barium, Ba	**0.11**	1	"	"	"	0.01	mg/L
Cadmium, Cd	ND	1	"	"	"	0.01	mg/L
Chromium, Cr	ND	1	"	"	"	0.01	mg/L
Selenium, Se	ND	1	"	"	"	0.01	mg/L
Lead, Pb	**1.04**	1	"	"	"	0.01	mg/L

EPA 7471A - Mercury by Cold Vapor Atomic Absorption

	Result	Dilution	Batch	Prepared	Analyzed	Reporting Limit	Units
Mercury, Hg	ND	1	TCLP_040219-01	4/2/2019	4/4/2019	0.1	µg/L

ND= Not Detected

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JONES ENVIRONMENTAL QUALITY CONTROL INFORMATION

Client: Hanwha Q CELLS America Inc.
Client Address: 400 Spectrum Center Dr., Suite 1400
Irvine, CA 92618

Attn: Ralph Alvarado

Report date: 4/4/2019
Jones Ref. No.: ST-13602

Date Sampled: 4/1/2019
Date Received: 4/1/2019
Date Analyzed: 4/3-4/2019
Physical State: Solar Panel - Q.PEAK DUO L-G5.2 XXX

BATCH: **TCLP_040219-01** **Prepared:** 4/2/2019 **Analyzed:** 4/3/2019

TCLP Metals by ICP-OES

	Result	Spike Level	% REC	% REC Limits	% RPD	Reporting Limit	Units
METHOD BLANK:	**TCLP_040219-MB1**						
Analytes:							
Silver, Ag	ND					0.01	mg/L
Arsenic, As	ND					0.01	mg/L
Barium, Ba	ND					0.01	mg/L
Cadmium, Cd	ND					0.01	mg/L
Chromium, Cr	ND					0.01	mg/L
Selenium, Se	ND					0.01	mg/L
Lead, Pb	ND					0.01	mg/L

ND= Not Detected

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JONES ENVIRONMENTAL QUALITY CONTROL INFORMATION

Client: Hanwha Q CELLS America Inc.
Client Address: 400 Spectrum Center Dr., Suite 1400
Irvine, CA 92618

Attn: Ralph Alvarado

Report date: 4/4/2019
Jones Ref. No.: ST-13602

Date Sampled: 4/1/2019
Date Received: 4/1/2019
Date Analyzed: 4/3-4/2019
Physical State: Solar Panel - Q.PEAK DUO L-G5.2 XXX

BATCH: **TCLP_040219-01** **Prepared:** 4/2/2019 **Analyzed:** 4/3/2019

TCLP Metals by ICP-OES

	Result	Spike Level	Source Result	% REC	% RPD	% REC Limits	Units
LCS:	**TCLP_040219-LCS1**						
Analytes:							
Silver, Ag	**5.10**	5.00		102%		80 - 120	mg/L
Arsenic, As	**5.93**	5.00		119%		80 - 120	mg/L
Barium, Ba	**5.32**	5.00		106%		80 - 120	mg/L
Cadmium, Cd	**5.26**	5.00		105%		80 - 120	mg/L
Chromium, Cr	**5.16**	5.00		103%		80 - 120	mg/L
Selenium, Se	**5.46**	5.00		109%		80 - 120	mg/L
Lead, Pb	**5.20**	5.00		104%		80 - 120	mg/L
LCSD:	**TCLP_040219-LCSD1**						
Silver, Ag	**5.13**	5.00	ND	103%	0.6%	80 - 120	mg/L
Arsenic, As	**5.96**	5.00	ND	119%	0.5%	80 - 120	mg/L
Barium, Ba	**5.22**	5.00	ND	104%	1.9%	80 - 120	mg/L
Cadmium, Cd	**5.17**	5.00	ND	103%	1.7%	80 - 120	mg/L
Chromium, Cr	**5.17**	5.00	ND	103%	0.2%	80 - 120	mg/L
Selenium, Se	**5.50**	5.00	ND	110%	0.7%	80 - 120	mg/L
Lead, Pb	**5.34**	5.00	ND	107%	2.7%	80 - 120	mg/L
CCV:	**TCLP_040219-CCV1**						
Silver, Ag	**0.95**	1.00	ND	95%		90-110	mg/L
Arsenic, As	**1.05**	1.00	ND	105%		90-110	mg/L
Barium, Ba	**0.96**	1.00	ND	96%		90-110	mg/L
Cadmium, Cd	**0.95**	1.00	ND	95%		90-110	mg/L
Chromium, Cr	**0.97**	1.00	ND	97%		90-110	mg/L
Selenium, Se	**1.00**	1.00	ND	100%		90-110	mg/L
Lead, Pb	**0.98**	1.00	ND	98%		90-110	mg/L

ND= Not Detected
RPD = Relative Percent Difference; Acceptability range for RPD is ≤ 15%

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JONES ENVIRONMENTAL QUALITY CONTROL INFORMATION

Client: Hanwha Q CELLS America Inc.
Client Address: 400 Spectrum Center Dr., Suite 1400
Irvine, CA 92618

Attn: Ralph Alvarado

Report date: 4/4/2019
Jones Ref. No.: ST-13602

Date Sampled: 4/1/2019
Date Received: 4/1/2019
Date Analyzed: 4/3-4/2019
Physical State: Solar Panel - Q.PEAK DUO L-G5.2 XXX

BATCH: **TCLP_040219-01** **Prepared:** 4/2/2019 **Analyzed:** 4/4/2019

EPA 7471A - Mercury by Cold Vapor Atomic Absorption

	Result	Spike Level	Source Result	% REC	% RPD	% REC Limits	Units
METHOD BLANK:	**TCLP_040219-MB1**						
Analytes:							
Mercury, Hg	ND						µg/L
LCS:	**TCLP_040219-LCS1**						
Mercury, Hg	**4.82**	5.00		96%		80 - 120	µg/L
LCSD:	**TCLP_040219-LCSD1**						
Mercury, Hg	**5.01**	5.00	ND	100%	**3.9%**	80 - 120	µg/L
CCV:	**TCLP_040219-CCV1**						
Mercury, Hg	**5.05**	5.00	ND	101%		90-110	µg/L

ND= Not Detected
RPD = Relative Percent Difference; Acceptability range for RPD is ≤ 15%

JONES ENVIRONMENTAL, INC.

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Chain-of-Custody Record

Client: Hanwha Q Cells	Date: 04/01/19
Project Name:	Client Project #:
Project Address:	
Email: Ralph-Alvarado ?@gmail.com	
Phone: 619-432-4100	
Report To: Dr. Wai Lo	Sampler:

Turn Around Requested:
- ☐ Immediate Attention
- ☐ Rush 24 Hours
- ☒ Rush 48 Hours
- ☐ Rush 72 Hours
- ☐ Normal

Report Options
EDD ____
EDF* - 10% Surcharge____
*Global ID ____________

LAB USE ONLY
Jones Project # ST-13602
Page 1 of 1

Sample Condition as Recieved:
Chilled ☐ yes ☐ no
Sealed ☐ yes ☐ no

Sample Container / Preservative Abbreviations
- AS - Acetate Sleeve
- SS - Stainless Steel Sleeve
- BS - Brass Sleeve
- G - Glass
- AB - Amber Bottle
- P - Plastic
- SOBI - Sodium Bisulfate
- MeOH - Methanol
- HCl - Hydrochloric Acid
- HNO3 - Nitric Acid
- O - Other (See Notes)

Analysis Requested

Sample ID	Date	Sample Collection Time	Laboratory Sample ID	Preservative	Sample Container	Sample Matrix: Soil (S), Sludge (SL), Aqueous (A), Free Product (FP)	TCLP									Hold	Number of Containers	Notes & Special Instructions
Sample 1			ST-13602-01				X											
Sample 2			ST-13602-02				X											
Sample 3			ST-13602-03				X											
Sample 4			ST-13602-04				X											

Relinquished By (Signature)	Printed Name	Received By (Signature)	Printed Name	Total Number of Containers
[signature]	S. Ralph Alvarado	[signature]	Chris Jones	
Company: Hanwha Q Cells	Date: 4/1/19 Time: 12:41pm	Company: JEC	Date: 04/01/19 Time: 1741	
Relinquished By (Signature)	**Printed Name**	**Received By Laboratory (Signature)**	**Printed Name**	
Company:	Date: Time:	Company:	Date: Time:	

Client signature on this Chain of Custody form constitutes acknowledgement that the above analyses have been reqested, and the information provided herein is correct and accurate.

Attachment 5: N.C. Clean Energy Technology Center Paper

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NC CLEAN ENERGY
TECHNOLOGY CENTER

Health and Safety Impacts of Solar Photovoltaics

MAY 2017

NC STATE UNIVERSITY

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 (SO_2), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$). 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 MW_{AC}) 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.

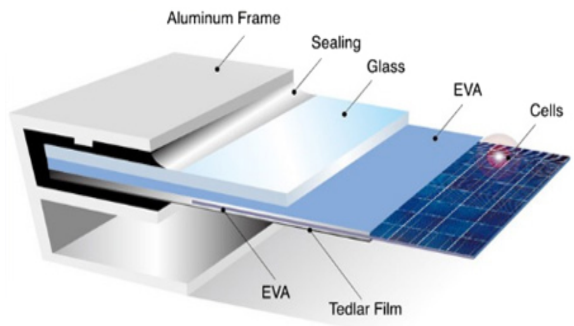

Figure 2: Components of crystalline silicon panels. The vast majority of silicon panels consist of a glass sheet on the topside with an aluminum frame providing structural support. Image Source: www.riteksolar.com.tw

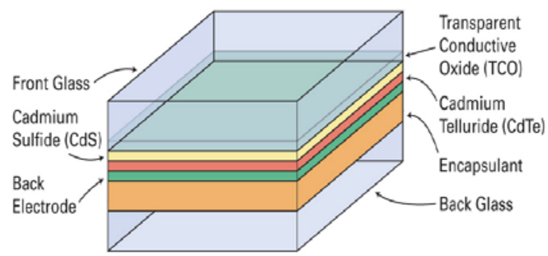

Figure 3: Layers of a common frameless thin-film panel (CdTe). Many thin film panels are frameless, including the most common thin-film panels, First Solar's CdTe. Frameless panels have protective glass on both the front and back of the panel. Layer thicknesses not to scale. Image Source: www.homepower.com

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 industry-standard 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 (SiO_2) 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 lead-based 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 MW_{AC}, which is generally 7 MW_{DC}) 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, cost-effectively 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 non-toxic 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-and-view 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.

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Attachment 6: Journal of Natural Resources and Development Article

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JOURNAL OF
NATURAL RESOURCES
AND DEVELOPMENT

Research note

Potential for leaching of heavy metals and metalloids from crystalline silicon photovoltaic systems

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Abstract

Photovoltaics (PV) are a rapidly growing technology as global energy sectors shift towards "greener" solutions. Despite the clean energy benefits of solar power, photovoltaic panels and their structural support systems (e.g., cement) often contain several potentially toxic elements used in their construction. Determining whether these elements have the potential to leach into surrounding environments should be a research priority, as panels are already being implemented on a large scale. In this study, we analyzed soil taken from beneath photovoltaic modules to determine if they are being enriched by metals (lead, cadmium, lithium, strontium, nickel, barium, zinc, and copper) and metalloids (selenium) present in panel systems. The soil samples were collected from directly beneath c-Si photovoltaic modules and adjacent fields. Samples were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES). Selenium, strontium, lithium, nickel, and barium levels measured in soil samples increased significantly in samples closer to PV systems. There were no significant differences in lead or cadmium levels near vs. far from the PV systems. Despite concentration differences for some elements near vs. far from the panel systems, no elements were, on average, present in concentrations that would pose a risk to nearby ecosystems. PV systems thus remain a cleaner alternative to traditional energy sources, such as coal, especially during the operation of these energy production systems.

1. Introduction

The demand and innovation of renewable energy systems is increasing as global temperature rises and fossil fuel reserves are exhausted (International Renewable Energy Agency, 2016). Current energy sectors are shifting towards renewable energy, with significant amounts of money ($285.9 billion: 2015) being invested in the development of wind, hydro, and photovoltaic systems (REN21, 2016). Photovoltaic (PV) systems are considered by some to be the most promising of renewable technology as they do not suffer from the same aesthetic and "not in my backyard" controversies as wind power (Good, 2006); nor do they have the same ecological impacts as the infrastructure used for hydroelectric production (Chen, Chen, & Fath, 2015). In 2015, the annual market of photovoltaic systems increased tenfold over the previous decade (REN21, 2016). This uptick in use has brought increasingly diverse applications of PV technology, including Tesla's solar roof tiles, solar vehicles such as Solar Impulse, and floating PV panels (Harvey, 2016; Vaughan, 2016). Given the potential scale of application of these systems, considering environmental impacts of PV panel installation is important; whether PV systems present any serious ecological risk to surrounding environments during their use is currently unknown.

Photovoltaic panels contain several components known to present health risks to both wildlife and human populations. Metals and metalloids commonly used in panels include cadmium (Cd) and selenium (Se) semiconductors, copper (Cu) wiring, nickel (Ni) and silver (Ag) contacts, tin (Sn) and lead (Pb) soldering, and strontium (Sr) and barium (Ba) doping used to increase panel efficiency (Silicon Valley Toxics Coalition, 2009). Furthermore, structural support components of the PV system, including cement foundations, may also leach hazardous elements into surrounding environments over time (Lu et al., 2016). Lead and Cd, in particular, are contaminants of concern in the solar panel industry due to both their abundance within panels as well as their highly toxic nature (Aman et al., 2015). For example, exposure to Pb can cause kidney and brain damage as well as mortality in humans (Silicon Valley Toxics Coalition, 2009). Lead is also well documented to reduce reproduction, increase behavior problems, and cause mortality in wildlife (Needleman, 2004; Tranel & Kimmel, 2009). Cadmium is toxic to the kidneys, blood, prostate, and respiratory system (Silicon Valley Toxics Coalition, 2009). Other metals found within PV materials that are also highly toxic include Ni and Cd, which are known carcinogens (Needleman, 2004; Silicon Valley Toxics Coalition, 2009); copper (Cu), which can cause kidney and liver damage; Se, which can cause selenosis, a disease of the respiratory system, as well as hair loss and nail brittleness (Silicon Valley Toxics Coalition, 2009); and Sr, which can have negative effects on bone development if consumed in large quantities (Agency for Toxic Substances and Disease Registry, 2004). Despite the known toxicity of these elements, currently there is little information regarding whether or not PV panel systems can leach metals and metalloids into their environments during normal operation.

Photovoltaic environmental life cycle analyses (LCAs) typically address upstream and downstream processes (Corcelli et al., 2018; Stoppato, 2008). A few studies do, however, discuss leaching of metals and metalloids. For example, Alsema, de Wild-Scholten and Fthenakis (2006) and Bohland and Smigielski (2000) both mention minuscule, non-harmful levels of cadmium leaching from panels. Other studies have broken up or ground PV panels into pieces and exposed them to solutions with a lower pH, mimicking acidic rain or waste water (Okkenhaug, Hauge, & Arp, 2010; Zapf-Gottwick et al., 2015). Specifically, Zapf-Gottwick et al. (2015) found significant amounts of Pb leached from panels, while Okkenhaug, Hauge, and Arp (2010) found only slightly elevated levels of Cd and Se leached in solution. However, in addition to having equivocal results, these lab studies were not done in the field during normal operation; thus, the question remains if panels leach harmful materials under realistic operating conditions.

The goal of this research is to determine if PV installations are capable of leaching their metal and metalloid components, especially Pb and Cd, into the environment at levels that are hazardous to both human and ecological health. To achieve this goal, we collected soil samples from beneath c-Si modules and from adjacent, module-free environments, and then compared bioavailable element concentrations between these samples. Accordingly, we asked the following questions: (1) Do soils near PV systems contain higher bioavailable concentrations of metals and metalloids? (2) Are bioavailable concentrations of metals and metalloids near PV systems of human health and ecological concern?.

2. Methods

Study Site

The PV installation sampled is a 750,000-watt installation at State University of New York at Buffalo. Each module consisted of monocrystalline silicon panels with a length of 1.64 m (64.6 in) and a width of 1.00 m (39.4 in). Panels were arranged in rows of twelve with a height ranging from one panel to eight. The modules were installed in the winter of 2011 through 2012, and became fully operational in April of 2012.

Sample Methods

Soil samples were collected in June of 2017. Starting at 100 ft from the edge of the outside modules, samples of about 500 g were collected every 15 ft following a 250 ft line parallel to a section of the PV modules. Working inwards to minimize possible contamination, samples were taken again at 45 ft and again at one final transect through the middle of the PV modules. Each of the five transects (100 ft, 45 ft, 0 ft) had a total of fifteen samples taken for a total of 45 samples collected.

200 g of each sample was then transferred to brown paper bags and dried for 48 hours at 65 °C. Samples were passed through a 2 mm sieve to remove large particulate matter. Samples were ground for 1 min using an agate mortar and pestle. The ground samples were then passed through a 0.125 mm sieve, with 2.5 mg of each being transferred to a 50 mL polypropylene centrifuge tube.

Metal Extraction

For the extraction process, we followed TCLP Method 1311 set forth by the U.S. Environmental Protection Agency (1992). Following the above protocol, because the pH of our soil solutions was >5, we used TCLP reagent number 2 U.S. Environmental Protection Agency (1992). Following the TCLP reagent number 2, 5.7 mL of Glacial Acetic Acid (CH_3CO_2H) was diluted with 1 L of nanopure water. The final pH of the solution was 2.86. Each 50 mL tube with 2.5 g of soil received 50 mL of the diluted CH_3CO_2H (20x the sample mass). The tubes were then rotated for 18 hours at 30 rpm. Four blank tubes filled with 50 mL of nanopure water accompanied each round of samples and were processed as controls. Acetic acid extraction is often used for determining leachable (i.e., bioavailable) fractions of metals in soil (Dean, 2010), and thus is appropriate for use in studies like ours that are interested in risk assessment to local ecosystems.

Sample Analysis

After rotation, samples sat overnight and then were decanted into 15 mL polypropylene centrifuge tubes using a pipette. They were then analyzed for Pb, Cd, lithium (Li), Sr, Ni, Ba, zinc (Zn), Cu, and Se using inductively coupled plasma optical emission spectrometry (ICP-OES), with results being reported in parts per million (ppm). We used ANOVA (SPSS 24; IBM) to compare element concentrations across our three sample transects.

3. Results

We found no difference in Cd concentrations ($F2,27 = 0.20$, $p = 0.82$; **Figure 1**) or Pb concentrations ($F2,27 = 2.08$, $p = 0.14$; **Figure 1**) along our distance gradient away from the panels. Selenium levels increased by 97 % from 100 ft to 0 ft in proximity to the PV panels ($F2,27 = 9.96$, $p < 0.01$; **Figure 1**), Li increased by 386 % ($F2,27 = 4.74$, $p = 0.02$; **Figure 1**), Sr increased by 86 % ($F2,27 = 4.89$, $p = 0.02$; **Figure 1**), Ni increased by 37 % ($F2,27 = 7.18$, $p < 0.01$; **Figure 1**), and Ba increased by 61 % ($F2,27 = 5.25$, $p < 0.01$; **Figure 1**). Zinc and Cu decreased significantly from the 100-foot mark to under the panels. Copper decreased by 1277 % ($F2,27 = 18.23$, $p < 0.01$; **Figure 1**) and Zn decreased by 195 % ($F2,27 = 21.32$, $p < 0.01$; **Figure 1**).

4. Discussion

In this study, we found that soil enrichment of Pb and Cd did not occur with closer proximity to PV systems. The values recorded for Se, Li, Sr, Ni, and Ba show a significant increase in concentration in soil closer to PV systems, while Zn and Cu increase significantly away from the systems. Below, we compare our results to soil concentration risk thresholds established by the Environmental Protection Agency's (USA) Ecological Soil Screening Level (Eco-SSL) risk assessment (U.S. Environmental Protection Agency, 2018), which is a conservative soil screening process that assumes soil metals are present in bioavailable form. In addition, we discuss the potential for leaching of potentially toxic elements from operational PV systems.

Several elements tested were either not variable across our distance gradient or were present in low concentrations that are not of immediate environmental concern. While studies suggest that Pb and Cd are the most common leachates from PVs (Okkenhaug, Hauge, & Arp, 2010; Zapf-Gottwick et al., 2015), Pb and Cd measured in this study were not elevated in soils near PV systems and were far below levels considered to be an imminent or future danger to environmental health [wildlife risk threshold for Pb: 11 µg - 1 g; for Cd: 0.36 µ - 1 g (U.S. Environmental Protection Agency, 2018)]. For intact PV panels, leaching of these elements is unlikely to occur, thus most of the concern for contamination of Pb and Cd from solar panels relates to panels disposed in landfills that degrade over time, and become exposed to water (Zapf-Gottwick et al., 2015). However, it is possible under operating conditions that PV panels can leach toxic elements if water penetrates into the modules through damaged areas, such as cracks in the module glass or through defective laminations. Thus, it appears that the modules studied here are intact and do not provide a mechanism for the leaching of internal Pb and Cd. Although Li, Ba, Ni, and Sr were recorded as significantly higher in soils beneath PV panels, the amounts recorded for these elements were all well below the soil screening values defined by the EPA and others (Shahzad et al., 2016; U.S. Environmental Protection Agency, 2018; 40 C.F.R. § 261.24, 1996); thus, the c-Si panels do not seem to pose a risk of contamination of these elements during normal operation.

Selenium was observed to be significantly higher in soils closer to our study PV panels. In contrast to the other recorded elements, the levels observed may be of concern. The Eco-SSL risk threshold soil values for Se are 0.52 µg - 1 g for plants, and 0.63 µg - 1 g for mammals (U.S. Environmental Protection Agency, 2018). In our study, the average Se concentration measured directly by the PV systems was 0.48 µg - 1 g , while the highest level of Se observed near the PV systems was 0.57 µg - 1 g. Thus, using the conservative risk thresholds established by the EPA's Eco-SSL, Se concentrations near the PV systems are approaching a level of environmental concern for local plants and other wildlife. However, over time, even low concentrations of certain elements can become problematic due to accumulation in soil and nearby organisms. Bioaccumulation of Se occurs in both aquatic and terrestrial ecosystems (Mann, Vijver, & Peijnenburg, 2011). A study done in association with the US Department of Agriculture (Bañuelos et al., 2002) addressing phytoremediation of Se found that the Se accumulated could be transferred to animals that consumed the plants. Likewise, deleterious effects of predators could occur if they were to consume these animals with elevated Se in their tissue (Mann, Vijver, & Peijnenburg, 2011). Environmental regulators have noted the potential of Se to integrate into trophic systems, and have thus set acceptable levels extremely low when compared to other metals and metalloids (Ministerie van Volkshuisvesting, 2000). Future studies examining leaching of elements from PV systems should consider indirect effects of these elements on ecosystems, including bioaccumulation by plants and animals near PV systems. C-Si panels are not known to contain appreciable amounts of Se, thus the source of Se observed in our study is unclear. In a similar study that examined both copper indium selenide (CIS) panels and cadmium telluride (CdTe) panels, Se in soil near CIS panels on roofs was found to be elevated by 0.3 µg per g when compared to surrounding soil.

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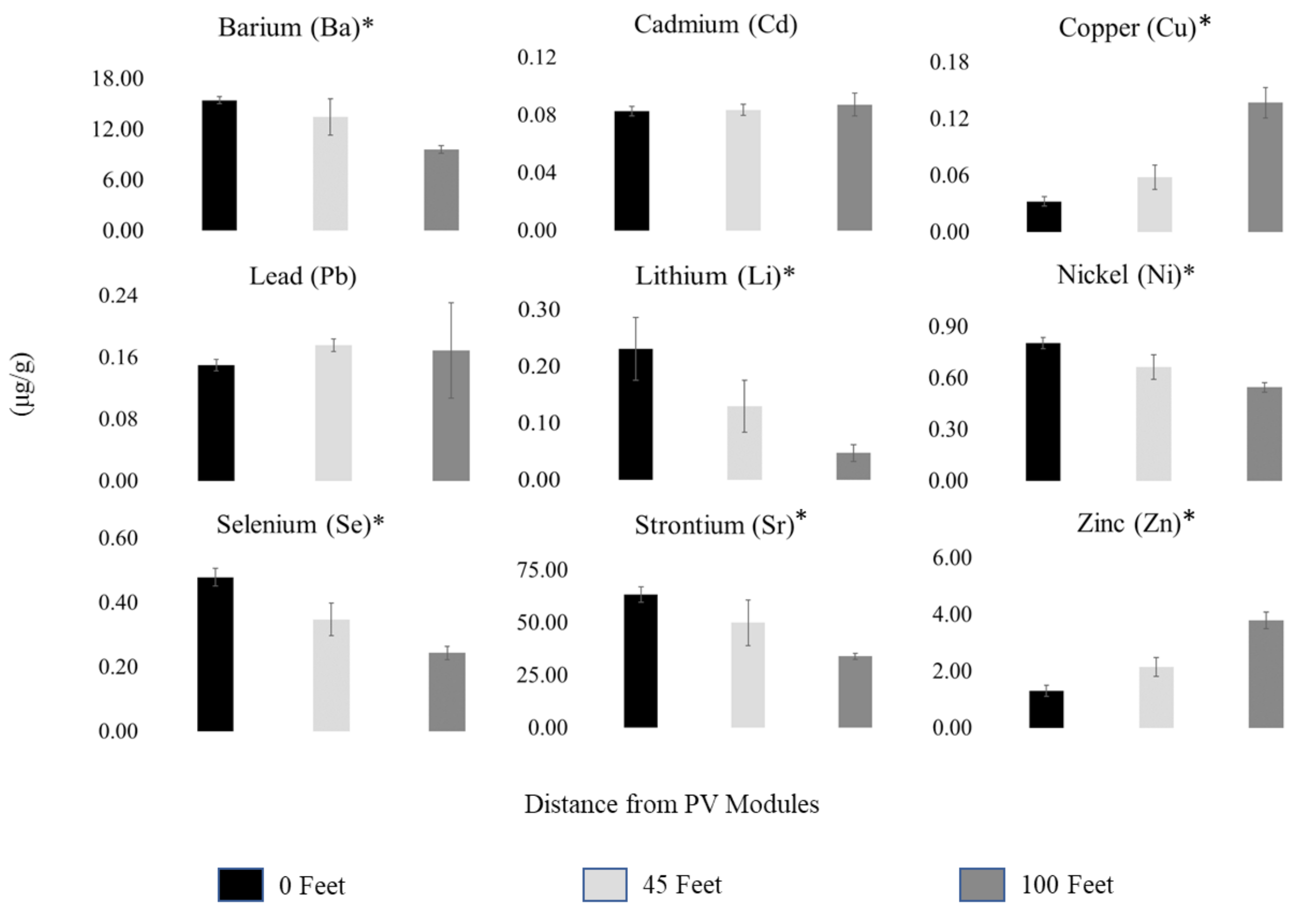

Figure 1: . Soil concentrations of barium (Ba), cadmium (Cd), copper (Cu), lithium (Li), nickel (Ni), lead (Pb), selenium (Se), strontium (Sr), and zinc (Zn) at varying distances from the photovoltaic panels. Asterisks indicate significant differences among groups.

Conversely, Se levels in soil near CdTe were not elevated (Steinberger, 1998). C-Si panels do not have Se concentrations as high as amounts reported in CIGS (Copper Indium Gallium Selenide) panels (Silicon Valley Toxics Coalition, 2009). Likewise, Sr, which is a new material to the PV panel industry, does not have an integral position to the manufacturing of PVs. The most common application currently for Sr in PV cells is to increase the efficiency of perovskite panels (Shai et al., 2017; Wu et al., 2018). However, c-Si panels, like those studied here, generally incorporate perovskite technology without Sr (Ba, Liu, & Shen, 2018).

Therefore, the source of metals and metalloids documented under the PV system in this study may be from system components other than the panels themselves. Terrestrial PV modules are constructed of c-Si panels mounted on aluminum frames, which are secured into the ground using cement. It is quite possible that the elevated levels of Se and other elements studied here are a result of the cement used in construction. An impact assessment study conducted on a quarry and cement plant in California found discharge from the plant contained levels of Se well over 50 mg^{-1} L. The source of this was identified as the limestone mined for use in cement (Nalbandian, 2012). Furthermore, in addition to metals being introduced in raw materials (e.g., Se and Sr in limestone), the production clinker granules within cement are often produced using coal fly ash additives, which can introduce metals such as Ba, Cr, and Ni (Cipurkovic et al., 2014). These metals may later leach from the cement into the environment following exposure to water under realistic environmental conditions (Lu et al., 2016). Thus, our reported increase of bioavailable metals and metalloids beneath the intact panels should prompt further investigation regarding PV system-wide pollution.

Overall, PV systems should still be considered a clean energy relative to traditional sources. In comparison, the amount of Pb in fly ash (product produced from coal combustion) is 7.00 µg^{-1}g, Cd is 0.093 µg^{-1} g and Se is 2.15 µg^{-1} g (Nalbandian, 2012). Although most of this contaminated fly ash may not affect the immediate vicinity, it is commonly disposed of in landfills and as a soil amendment in agriculture (Haynes, 2009). Despite toxic metal components, the PV panel industry is growing at such a fast pace that innovation should quickly phase out the use of harmful substances.

Examples of this include use of materials other than Pb for soldering as well as using organic materials as semiconductors instead of metals and metalloids (Kippelen, & Brédas, 2009). However, until these advancements occur industry-wide (e.g., organic materials are not yet commercially used as semiconductors due to low efficiency and stability; (Burlingame et al., 2018)), further studies are needed to determine the extent of leaching that occurs using current PV technology. While TLCP analyses of solar panels are common place for waste characterization [e.g., Okkenhaug, Hauge, & Arp, 2010), there is a paucity of studies that assess potential for leaching of toxic elements from PV systems during active operation.

We conclude that while no elements were, on average, above soil screening thresholds established by the EPA's Eco-SSL, further studies are needed to determine the impacts of PV system installation and operation on terrestrial ecosystems. PV systems, however, remain a cleaner alternative to traditional energy sources, such as coal, especially during the operation of these energy production systems.

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