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HEALTH AND SAFETY IMPACTS OF SOLAR PHOTOVOLTAICS

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Executive Summary

As the prevalence of solar photovoltaic (PV) systems grows, including in leading states like North Carolina, questions have emerged about potential public health and safety impacts. This white paper examines those concerns by reviewing peer-reviewed literature, engineering and safety standards, operational procedures, and relevant regulations. The findings show that solar PV systems pose minimal risk to public health and safety.

Hazardous Materials and Components

In general, solar panels, construction, and components do not pose significant health or safety risks due to their material composition.

Solar panels are mainly made from glass, polymers, aluminum, copper, and semiconductor materials.

Semiconductor materials may contain certain metals of varying toxicity, such as lead, cadmium, and tellurium, while the other materials are non-toxic and non-hazardous.

Panels may be made of silicon, which is non-toxic and non-hazardous, cadmium telluride, which contains cadmium bound to a stable compound and encapsulated in layers of glass and plastic, and copper indium gallium

selenide, which are generally non-toxic and are again contained within glass and plastic. Panels use a small amount of lead for solder, but manufacturers are moving towards lead-free designs.

PV cells are encapsulated in ethylene-vinyl acetate (EVA) between tempered glass and polymer layers, preventing corrosion and leakage of panel materials. Protective glass coatings maintain performance, though there is concern as to the presence of per- and polyfluoroalkyl substances (PFAS) in coatings. At present, there is no evidence that solar panels are a significant source of PFAS. Depending on the recycling method used, most of the glass, polymers, and metals in a panel can be recovered at the end of life.

The average solar panel lasts about 25 years, with warranties ensuring at least 80% of original output. Operational lifespans are now typically 25–35 years, and research is exploring panels that could last up to 50 years. Developers generally plan for a minimum lifespan of 30 years. Panels and mounting structures are built to handle local wind speeds, with many rated up to 150 mph. They have proven resilient in hurricanes, including Sandy (2012), Matthew (2016), and Helene (2024). Hail is the most common source of damage, and hail-resistant modules are recommended in high-risk areas.

Property insurance usually covers catastrophic damage, and adequate coverage is a standard business practice and often required by financiers.

Non-panel components are also low risk. Racking systems are typically galvanized steel or aluminum—stable, common, and non-toxic. Inverters are enclosed in weatherproof steel housings, and their cooling systems operate similarly to those found in computers. Some high-voltage equipment, like transformers and circuit breakers, use sulfur hexafluoride (SF₆) for insulation and arc suppression. SF₆ is non-toxic, non-flammable, and stable, and its use is regulated nationwide. Its use is not unique to solar installations. Modern transformers also do not pose the same risks as older units, which contained polychlorinated biphenyls (PCBs) and were banned in 1979.

Safety Factors

Solar PV systems, like most consumer electronics, produce non-ionizing electromagnetic fields (EMF), which are low-energy and cannot damage DNA. EMF levels from solar panels, inverters, and batteries are well below public exposure limits and similar to common household appliances. EMF strength drops quickly with distance, so people outside the facility are not at risk. Even sensitive devices like pacemakers are unaffected.

Electrical components—panels, inverters, transformers, and battery systems—pose shock and arc flash risks. Proper training, protective equipment, and site security can minimize risk, and unauthorized personnel should never access high-voltage areas.

Most panel materials are non-flammable, with only minor polymer components carrying limited risk. Fires are rare and usually caused by wiring faults, hot spots, or external stressors. PV fires are far less frequent than wildfires and can be managed with good design, installation, and maintenance. Rooftop panels can affect firefighter ventilation, but updated building codes, National Electric Code requirements, and training reduce hazards.

Lithium-ion battery energy storage systems are generally safe but require proper recycling and operational fire safety measures. Existing codes, standards, and specialized training help mitigate risk.

End-of-Life Management

By 2050, projected U.S. solar panel waste (7.5–10 million tons) will likely make up less than 3% of total solid waste, smaller than plastics or fossil fuel waste, while recycling rates are improving. While recycling has historically been more expensive than landfilling, costs are declining, and valuable materials can be recovered, adding to potential value streams. Most

states in the U.S. require decommissioning plans for large-scale solar facilities, and national programs and services led by the Solar Energy Industries Association (SEIA) and solar recycling companies are expanding recycling networks.

As a comparison, wind energy could generate 2.2–113 million metric tons of solid waste depending on deployment levels, with up to 90% of wind materials being recyclable; and coal produces 70–100 million tons of solid waste every year.

Most modern crystalline silicon and CdTe panels pass the U.S. Environmental Protection Agency's (EPA) Toxic Characteristic Leaching Procedure (TCLP) test and are classified as non-hazardous waste. Studies show very limited leaching risk, even in worst-case scenarios. Responsible end-of-life management is important, but solar panels are safe for landfills,

increasingly recyclable, and their environmental benefits outweigh potential disposal concerns.

Conclusion

When installed and operated in accordance with established engineering, safety, and regulatory standards, solar PV systems present limited adverse effects to public health and safety. Evaluating potential hazardous materials, EMF exposure, electrical safety, and fire risk indicate that overall danger is low. Compared to fossil-fuel generation, solar PV systems deliver substantial environmental gains by reducing carbon emissions, solid waste, and heavy metal poisoning, and protecting air quality. Overall, the analysis presented supports the conclusion that solar PV systems are safe and carry minimal public health risks.

Introduction

Solar photovoltaic (PV) systems have become increasingly common in North Carolina over the last several decades. In fact, North Carolina is often ranked among the top 5 solar-producing states in the nation. In spite, or perhaps because, of the relative success of the solar PV industry, public opinion and public understanding of this technology are still susceptible to numerous myths, half-truths, and misconceptions. Additionally, as the solar industry grows and matures, newer systems incorporate new technologies, tools, and approaches (e.g., batteries, new PV chemistries, and new land use) while older systems come offline and are retired and decommissioned. These new circumstances in the solar industry are also due for a public-facing explainer to show solar customers and their neighbors that there is no significant cause for concern.

Solar 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 relatively 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. Additionally, there are predictable occupational hazards to solar installers, which can be easily mitigated through worker protections and standard health and safety practices. 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 minimal quantities.

Due to the reduction in the pollution from fossil-fuel-fired electric generators, the overall impact of solar development on human health is overwhelmingly positive. This pollution reduction results from a partial replacement of fossil-fuel-fired generation by emission-free PV-generated electricity, which reduces harmful sulfur dioxide (SO₂), nitrogen oxides (NO_x), and fine particulate matter (PM_{2.5}). Analysis from the National Laboratory of the Rockies (NLR, formerly the National Renewable Energy Laboratory) and Lawrence Berkeley National Laboratory (LBNL), both affiliates of the U.S. Department of Energy (DOE), 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.^{1,2,3} 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.

Large-scale installation of PV technologies has been ongoing for the last decade, and 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 North Carolina and elsewhere to address the health and safety risks associated with solar PV technology. These risks associated with solar PV technology are minimal and substantially lower than those arising from common land-use activities such as road transport or industrial development and are strongly outweighed by the health benefits of generating clean electricity.

¹ Biswas, A., Qiu, M., Braun, D., Dominici, F., Mork, D. "Quantifying Effects of Solar Power Adoption on CO₂ Emissions Reduction." *Science Advances*. July 2025.

² Rivera, N. M., Ruiz-Tagle, J. C., Spiller, E. "The Health Benefits of Solar Power: Evidence from Chile." *Journal of Environmental Economics and Management*. July 2024.

³ Millstein, D., O'Shaughnessy, E., Wisner, R. "Climate and Air Quality Benefits of Wind and Solar Generation in the United States from 2019-2022." *Cell Reports Sustainability*. May 2024.

This paper addresses the potential health and safety impacts of solar PV in North Carolina, with a brief look at integrated battery energy storage systems (BESS), organized into the following four categories:

1. Hazardous Materials
2. Electromagnetic Fields (EMF)
3. Electric Shock and Arc Flash Hazards
4. Fire Safety

1. Hazardous Materials

One of the more common concerns about 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 gain an understanding of the low potential for toxic hazards coming from a solar project, one must understand solar module construction, system installation, materials used, the panel end-of-life protocols, and system operation. This section will examine these aspects of a solar project and the potential for toxicity impacts in project installation and construction, system components, and operations and maintenance.

1.1 Project Installation and 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 lay out 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 activated.

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.⁴ Today there are two main PV technologies used in PV panels at utility-scale solar facilities: silicon and thin film. These two technology types make up 97% of the market.⁵ As of 2025,

⁴ Abdo, D. M., El-Shazly, A. N., Medici, F. "Recovery of Valuable Materials from End-of-Life Photovoltaic Solar Panels." *Materials (Basel)*. April 2023.

⁵ Svetz, M. Solar Panel Components: Safety." *PennState Extension*. January 2024.

all thin film used in North Carolina solar facilities are cadmium telluride (CdTe) panels from the U.S. manufacturer, First Solar. The manufacturer also operates in South Carolina, having announced in late 2025 the development of a 3.7 GW module production facility in Cherokee County.⁶



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. There are other thin-film PV panels

⁶ <https://extension.psu.edu/solar-panel-components-safety#:~:text=The%20average%20amount%20of%20lead%20in%20a,link%20the%20individual%20cells%20within%20the%20panel>.

⁶ Norman, W. "First Solar to build new 3.7GW module facility in South Carolina." *PV Tech*. October 2025. <https://www.pv-tech.org/first-solar-to-open-new-3-7gw-us-manufacturing-plant-in-2026/>

available on the market, such as Solar Frontier's copper indium gallium selenide (CIGS) panels. 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 copper indium selenium (CIS)/CIGS respectively. The rest of this section applies equally to both silicon and thin-film panels.

To keep out air and moisture, PV cells are encapsulated between two layers of plastic, providing decades of corrosion-free operation. The encapsulation layers are protected on the top with a layer of tempered glass and on the backside with a polymer sheet. Frameless and bifacial 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. Thus, a damaged module does not generally create small pieces of debris; instead, it largely remains together as one piece.

Nearly all panels include some kind of glass coating. These coatings are designed to protect the PV material and

keep it clean, and depending on the choice of material, they can actually reduce operations and maintenance expenses. The glass coating on solar panels, much like glass on any surface (like the windows on buildings), can cast a glare from reflected sunlight. Because solar panels work by absorbing light, any reflected light is wasted energy; thus, many solar panels use anti-reflective coatings to absorb more light and cast less glare.⁷ Modern solar panels cause less glare than some office building windows. Still, glare can be an issue in some urban settings and especially at airports. Glare can be further mitigated by requiring developers to perform glint and glare studies and through orientation and siting of the solar array itself; notably, adjusting the angle of solar panels to mitigate glare, particularly at airports, can be done in such a way as to maintain optimal energy output.⁸

There are growing concerns about the use of per- and polyfluoroalkyl substances (PFAS) in all kinds of construction and consumer goods, including solar panel coatings and components. PFAS are of concern because they are forever chemicals, i.e., once they are introduced into the

⁷ "Solar Panel Glare: Is it an issue?" Penn State Extension.

<https://extension.psu.edu/solar-panel-glare-is-it-an-issue>

⁸ Kim, C. *et al.* "Glare-Free Airport-Based Photovoltaic System via Optimization of Its Azimuth Angle." Sustainability, 2022.

environment, they do not break down and can easily increase in concentration as they move up the food chain. They have been linked to certain cancers and other health impacts. However, to date, studies have not found that solar panels are a significant source of PFAS pollution.⁹

It is widely accepted and recognized that PV panels have a roughly 25-year lifetime, after which they must be decommissioned and properly disposed of or recycled.¹⁰ These power warranties guarantee a PV panel will produce at least 80% of its original nameplate production after 25 years of use. A 2020 survey conducted by LBNL of U.S. solar industry professionals indicates that the average operational lifespan of solar panels has steadily increased from about 20 years in 2007 to an estimated 25–35 years by 2025. The survey further notes that project developers typically plan for a minimum project lifespan of 30 years.¹¹ Meanwhile, NLR is researching ways to manufacture panels that will last 50 years.¹²

⁹ Nain, P. and Anctil, A. “Per- and polyfluoroalkyl substances (PFAS) in solar photovoltaic modules.” *Renewable and Sustainable Energy Reviews*. June 2025.

¹⁰ Xia S., Yang Y., Poon J. P. H. “How to tackle the looming challenge of solar PV panel recycling.” *Proc Natl Acad Sci U S A*. July 2025.

¹¹ Wiser R., Bolinger M., Seel J. “Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals.” *Lawrence Berkeley National Laboratory*. June 2020.

¹² “FY2021 Annual Report.” *DuraMAT*. 2022. <https://docs.nrel.gov/docs/fy22osti/82148.pdf>

Moreover, 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 was 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.¹³ In the fall of 2016, the U.S. 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.¹⁴ Both ground-mounted and rooftop solar systems also weathered Hurricane Helene in September 2024, delivering power to homes and communities despite outages and damage to the electrical grid across the

¹³ David Unger. “Are Renewables Stormproof? Hurricane Sandy Tests Solar, Wind.” *Christian Science Monitor*. November 2012. <https://www.csmonitor.com/Environment/Energy-Voices/2012/1119/Are-renewables-stormproof-Hurricane-Sandy-tests-solar-wind>.

¹⁴ Rogers, M. & Phillips, R. “Tracking Your Solar Investment: Best Practices for Solar Tracker O&M.” *NEXTracker*. March 2017.

state.¹⁵ While storm hardening solar installations can be costly, it has been shown to protect them from all but the worst of extreme weather.¹⁶

The most common weather event that leads to solar panel damage is hail. When installing solar panels, customers should consider hail risk for their area, and if the risk is high, installing hail-resistant modules outright instead of retrofitting later or incurring large repair costs.¹⁷ Even if hail does damage a solar panel or installation, the damage can be repaired, and if left unrepaired, the broken panels and modules pose no additional risks that other broken glass or equipment may also pose.¹⁸

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 clean up and repair the project. It is in the best interest of the system owner to

¹⁵ Langone, Alix. "Will your solar panels survive the next hurricane?" *EnergySage*. August 2025. <https://www.energysage.com/news/solar-panel-s-withstand-hurricanes/>

¹⁶ Elsworth, J. and von Vleet, O. "Solar Photovoltaics in Severe Weather: Cost Considerations for Storm Hardening PV for Resilience." *NREL*. June 2020. f

¹⁷ "Hail Damage Mitigation for PV Systems," U.S. Department of Energy. <https://www.energy.gov/femp/hail-damage-mitigation-pv-systems>

¹⁸ "Why you don't need to worry about broken solar panels," Solar Energy Industries Association. <https://seia.org/blog/why-you-dont-need-worry-about-broken-solar-panels/>

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 is 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 PV cells, the small electrical leads connecting them together, and the wires coming out of the back of the panel. The electricity-generating and conducting components make up less than 5% of the weight of most panels. The PV cell itself is nearly 100% silicon, and silicon is the second most common element in the Earth's crust. The silicon for PV cells is obtained by high-temperature processing of quartz sand (SiO₂) that removes its oxygen molecules. The refined silicon is converted to a PV cell by adding minuscule 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 anti-reflective 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 the cell.¹⁹ In order for the front and

¹⁹ Honsberg, C. and Bowden, S. "Overview of Screen Printed Solar Cells." *PV Education*. <https://www.pveducation.org/pvcdrom/manufacturing-si-cells/screen-printed-solar-cells>

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 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 glass frit and the solder is the only part of silicon PV panels with the 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 mean 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, advances in lead-free solders have spurred a trend among PV panel manufacturers to reduce or remove the lead in their panels. In 2024, the Solar Scorecard, a ranking initiative led by the Solar Scorecard Project (formerly the Silicon Valley Toxics Coalition) in collaboration with the Collaboratory for a Regenerative Economy (CoRE) tracked the environmental responsibility of solar PV manufacturers.²⁰ The report details that crystalline silicon panel manufacturers Mitsubishi and REC have successfully transitioned to lead-free solders. Even more in particular, Mitsubishi has solder-free cells, and REC has eliminated lead from all of its panel components. While these companies are moving towards lead-free materials, the solar industry at large has not yet determined best practices for materials data and information sharing to reduce hazardous material use.

The report also identifies solar PV manufacturers that have achieved Electronic Product Environmental Assessment Tool (EPEAT) certification, a global ecolabel for electronics and technology products, including solar PV modules. The certification is administered by the Global Electronics Council and ranks eligible products as

²⁰ "The Solar Scorecard: Measuring and Managing Vulnerabilities in the Solar Energy Industry." *Clean Production Action, CoRE, Solar Scorecard Project*. 2024.

Bronze, Silver, or Gold based on a set of environmental performance criteria. These criteria focus on four impact areas: climate change mitigation, sustainable use of resources, chemicals of concern (e.g., lead, PFAS, and cadmium), and responsible supply chains.²¹

In the U.S., as of 2025, silicon PV panel manufacturer Qcells is currently the only manufacturer to attain EPEAT certification for silicon PV panels.²² Qcells was registered in 2024 at the Bronze level, reflecting the company's sustainability leadership through its efforts to address key environmental impacts across the product life cycle. Regarding lead content, the manufacturer's laminate components contain less than 0.1% lead²³, meeting the requirements of the European Restriction of Hazardous Substances (RoHS) Directive, a globally recognized, long-standing standard that is complementary to EPEAT.

²¹ "EPEAT® Criteria." *Global Electronics Council*®. 2026.

<https://epeat.net/about/epeat-criteria#:~:text=Increase%20knowledge%20&%20publicly%20disclose%20chemical,metals%2C%20chlorinated%20compounds%20and%20phthalates>

²² "Product Finder." *Global Electronics Council*®. 2026.

<https://epeat.net/product-finder?refinementList%5Bcategory%5D%5B0%5D=Photovoltaic%20Modules%20and%20Inverters&refinementList%5Btype%5D%5B0%5D=Photovoltaic%20modules&refinementList%5Bcountry%5D%5B0%5D=United%20States>

²³ "Product Safety Data Sheet." *Qcells*. March 2023.

Meeting the RoHS Directive's standards means that the amount of cadmium and lead in the panels they manufacture falls below the directive's thresholds, which are set by the European Union and serve as an internationally recognized standard for hazardous substances in manufactured goods.²⁴ The RoHS Directive requires that the maximum concentration found in any homogenous material in a product be less than 0.01% cadmium and less than 0.10% lead; therefore, any solder can be no more than 0.10% lead.²⁵

While some manufacturers are producing PV panels that meet the RoHS standard, such as Qcells and JinkoSolar²⁶, there is no requirement that they do so because the RoHS Directive explicitly states that the directive does not apply to PV panels.²⁷ The justification for this is provided in item 17 of the current RoHS Directive:

²⁴ "2015 Solar Scorecard." *Silicon Valley Toxics Coalition*. 2015.
<https://trellis.net/article/sunpower-solarworld-to-p-2015-solar-scorecard/>

²⁵ "Recast of Reduction of Hazardous Substances (RoHS) Directive." *European Commission*. September 2016.
http://ec.europa.eu/environment/waste/rohs_ee_Re/index_en.htm

²⁶ "PV Module FAQs." *JinkoSolar*. 2026.
<https://jinkosolar.eu/solar-panels/pv-modules/>

²⁷ "DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment." *Official Journal of the European Union*. June 2011.
<http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0065&from=en>

"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."

Estimates for the lead in a single PV panel with lead-based solder range from 1.6 to 24 grams of lead, with 13 g (less than half of an ounce) per panel seen most often in the literature.²⁸ At 13 g/panel, each panel contains one-half of the lead in a typical 12-gauge shotgun shell.²⁹ This amount equates to roughly 1/750th of the lead in a single car

²⁸ Giacchetta, G., Leporini, M., Marchetti, B. "Evaluation of the Environmental Benefits of New High Value Process for the Management of the End of Life of Thin Film Photovoltaic Modules." July 2013.
www.researchgate.net/publication/257408804_Evaluation_of_the_environmental_benefits_of_new_high_value_process_for_the_management_of_the_end_of_life_of_thin_film_photovoltaic_modules

²⁹ "Study on Photovoltaic Panels Supplementing The Impact Assessment for a Recast of the WEEE Directive." *European Commission*. April 2011.

battery. In a panel, it is all durably encapsulated from air or water for the full life of the panel.³⁰

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.^{31,32} 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.^{33,34} For more information about PV panel

³⁰ Miller, C. "Lead-Acid Batteries 3034." *Waste 360*. March 2006.
http://waste360.com/mag/waste_leadacid_batteries_3

³¹ Okkenhaug, G. "Leaching from CdTe PV module material results from batch, column, and availability tests." *Norwegian Geotechnical Institute*. 2010.

³² Zapf-Gottwickl, R. et al. "Leaching Hazardous Substances out of Photovoltaic Modules." *International Journal of Advanced Applied Physics Research*. December 2015.

³³ Ibid.

³⁴ Sinha, P., et al. "Evaluation of Potential Health and Environmental Impacts from End-Of-Life Disposal of Photovoltaics." 2014.

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 minimal 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 CdTe PV panel. In the U.S., the share of CdTe PV panels manufactured makes up more than 30% of the utility-scale PV market.³⁵ Research demonstrates that they pose negligible toxicity risk to public health and safety while potentially reducing the public's exposure to cadmium by reducing coal emissions. As of Q3 2025, North Carolina had roughly 9.7 GW of installed solar capacity.³⁶ CdTe accounts for 16% of nationwide solar installations, so by that estimate, CdTe may account for roughly 1.55 GW in North Carolina.³⁷

³⁵ Meagley, R. et al. "Cadmium Telluride Photovoltaics Perspective Paper." *U.S. Department of Energy*. January 2025.

³⁶ "North Carolina State Solar Overview." *Solar Energy Industries Association*. 2025.

³⁷ Meagley, R. et al. "Cadmium Telluride Photovoltaics Perspective Paper." *U.S. DOE Solar Energy Technologies Office*. January 2025.

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.³⁸ Research has indicated that the tiny amount of cadmium in these panels does not pose a health or safety risk.³⁹

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, which has 1/100th the toxicity of free cadmium.^{40,41} 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

³⁸ Bonnet, D. and Meyers, P. "Cadmium-telluride—Material for thin film solar cells." *Journal of Materials Research*. 1998.

³⁹ Fthenakis, V. and Zweibel, K. "CdTe PV: Real and Perceived EHS Risks." *National Center for Photovoltaics and Solar Program Review Meeting*. March 2003.

⁴⁰ Fthenakis, V. "CdTe PV: Facts and Handy Comparisons." January 2003. <https://www.semanticscholar.org/paper/CdTe-PV%3A-Facts-and-Handy-Comparisons-Fthenakis/f103bd7488913007a1ae0f1eadf85f6fdf8aa6f3>

⁴¹ Kaczmar, S., "Evaluating the Read-Across Approach on CdTe Toxicity for CdTe Photovoltaics." *SETAC North America 32nd Annual Meeting*. November 2011.

glass and encloses over 99.9% of the cadmium in the molten glass.⁴²

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.⁴³ Even though North Carolina produces a considerable portion 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. Additionally, though there are toxic metal emissions associated with both PV manufacturing and the burning of fossil fuels, PV panels have considerably lower lifecycle greenhouse gas emissions.

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

⁴² V. M. Fthenakis et al. "Emissions and Encapsulation of Cadmium in CdTe PV Modules During Fires." *Progress in Photovoltaics*. May 2005. <https://onlinelibrary.wiley.com/doi/10.1002/pip.624>

⁴³ "Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems." *International Energy Agency*. March 2015. <http://iea-pvps.org/index.php?id=315>

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.⁴⁴ 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.⁴⁵

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,⁴⁶ similar to the process used to recycle CdTe panels. Like many silicon-based panels, CdTe panels are

⁴⁴ Fthenakis, V.M. "Life Cycle Impact Analysis of Cadmium in CdTe Photovoltaic Production," *Renewable and Sustainable Energy Reviews*. 2004.

⁴⁵ Weckend, S., Wade, A, and Heath, G. "End of Life Management: Solar Photovoltaic Panels." *International Renewable Energy Agency*. June 2016.

⁴⁶ Zapf-Gottwickl, R. et al. "Leaching Hazardous Substances out of Photovoltaic Modules." *International Journal of Advanced Applied Physics Research*. January 2015.

reported (as far back as 1998⁴⁷) to pass the U.S. Environmental Protection Agency's (EPA) Toxic Characteristic Leaching Procedure (TCLP) test, which tests the potential for crushed panels in a landfill to leach hazardous substances into groundwater.⁴⁸ Passing this test means that they are classified as non-hazardous waste and can be deposited in landfills.^{49,50} For more information about PV panel end-of-life, see the Panel Disposal section.

There is also concern about 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.

⁴⁷ Cunningham D. "Discussion about TCLP protocols." *Photovoltaics and the Environment Workshop*. July 1998.

<https://www.osti.gov/servlets/purl/759023>

⁴⁸ Sinha, P., et al. "Evaluation of Potential Health and Environmental Impacts from End-Of-Life Disposal of Photovoltaics," *Photovoltaics*, 2014.

⁴⁹ Fthenakis, Vasilis M. "Chapter VII-2, Practical Handbook of Photovoltaics: Fundamentals and Applications, General editors T. Markvart and L. Castaner, to be published by Elsevier in 2003. ISBN 1-856-17390-9 OVERVIEW OF POTENTIAL HAZARDS." December 2003.

<https://www.semanticscholar.org/paper/Chapter-VII-2-Practical-Handbook-of-Photovoltaics-%3A-Fthenakis/504fcfc128f17c1d99784a8d9da8a06460b4adb3>

⁵⁰ Okkenhaug, G., Audun, H., and Hans P. H. Arp. "Environmental risks regarding the use and end-of-life disposal of CdTe PV modules." 2010.

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 seawater will exceed the environmental regulation values.”⁵¹ 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.⁵²



First Solar, the U.S. and EPEAT-certified manufacturer and the only significant supplier of CdTe panels, has a robust panel take-back and recycling program that has been operating commercially since 2005.⁵³ The company states that it is “committed to providing a commercially attractive recycling solution for PV power plant and module owners to help them meet their module (end of life) EOL obligation simply, cost-effectively, and responsibly.” First Solar provides global recycling services to their customers to collect and recycle panels once they reach the end of their 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

⁵¹ Matsuno, Y. “Environmental Risk Assessment of CdTe PV Systems to be considered under Catastrophic Events in Japan.” December 2013.

⁵² Sinha, P. and Wade, A. “Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of PV Module Field Breakage.” *IEEE*. 2015.

⁵³ “Responsible Solar: First Solar Leads Industry with Validated Environmental and Social Performance and Transparent Reporting.” *Business Wire*. September 2024. <https://www.businesswire.com/news/home/20240909937420/en/Responsible-Solar-First-Solar-Leads-Industry-with-Validated-Environmental-and-Social-Performance-and-Transparent-Reporting>

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).⁵⁴ The cells typically 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.⁵⁵ In 2015, a CIGS manufacturer based in Japan, Solar Frontier, 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. Notably, these panels are RoHS compliant, thus

⁵⁴ “40 CFR §261.24. Toxicity Characteristic.” *Code of Federal Regulations*. May 2017. https://www.ecfr.gov/cgi-bin/text-idx?node=se40.26.261_124&rgn=div8

⁵⁵ “Copper Indium Gallium Diselenide.” *Office of Energy Efficiency & Renewable Energy*. <https://www.energy.gov/eere/sunshot/copper-indium-gallium-diselenide>

meeting the rigorous toxicity standard adopted by the European Union even though this directive exempts PV panels. The authors are unaware of any completed or proposed utility-scale systems in North Carolina using CIS/CIGS panels, though several projects do exist across various parts of the country, including from Solar Frontier in California and Indiana.^{56,57}

1.2.3 Panel End-of-Life Management

Concerns about the volume, disposal, toxicity, and recycling of PV panels are addressed in this subsection. As of 2025, modern utility-scale solar installations are expected, on average, to have useful lifetimes of 30 years or more.⁵⁸ Improvements in the durability and longevity of solar panels extend their useful life, easing near-term

⁵⁶ “Solar Frontier Americas Development Announces Ribbon Cutting Event for 20 MW Solar Power Generation Plant in Southern California.” *Idemitsu Renewables*. January 2016. <https://idemitsurenouvelables.com/solar-frontier-americas-development-announces-ribbon-cutting-event-for-20-mw-solar-power-generation-plant-in-southern-california/>

⁵⁷ Pickerel, K. “Case Study: Solar Frontier CIS modules installed on two Indiana utility-scale projects.” *Solar Power World*. August 2016. <https://www.solarpowerworldonline.com/2016/08/case-study-solar-frontier-cis-modules-installed-two-indiana-utility-scale-projects/>

⁵⁸ Wisner, R., Bolinger, M., and Seel, J. “Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals.” *Lawrence Berkeley National Laboratory*. June 2020.

end-of-life pressures while still underscoring the need for long-term management strategies.

To put the volume of PV waste into perspective, consider that by 2030, the U.S. is expected to produce between .17 and 1 million tons of solar panel waste,⁵⁹ or, according to NLR, around 3,000 football fields worth of solar panel waste.⁶⁰ By 2050, the range will balloon to 7.5 to 10 million tons.⁶¹ As of 2018, the EPA estimates that the U.S. produces about 300 million tons of solid waste each year, meaning that retired solar panels will account for less than 3% of total U.S. solid waste by 2050.⁶² For comparison, wind components are projected to contribute 2.2 million metric tons of solid waste by 2050 under historical deployment projections and as much as 113 million metric tons of waste by 2050 under very high

deployment scenarios.⁶³ However, up to 90% of wind materials can be recycled, so this figure can be mitigated. This number is minimal compared to coal, which produces (in addition to greenhouse gases) 70-100 million tons annually of ash, slag, and other solid waste.⁶⁴ Comparatively, the relative size of the solar waste that will accumulate by 2030, 2040, and 2050 is still predicted to be smaller than other waste streams, including plastic waste and coal ash.⁶⁵ In the U.S., end-of-life disposal, including recycling, of solar products is governed by the Federal Resource Conservation and Recovery Act (RCRA), as well as state policies in some situations.

Instead of sending modern panels to the landfill, they can be recycled to recover valuable and critical materials. As of November 1, 2025, the State of North Carolina requires that all solar facilities of 2 MW or greater have a decommissioning plan that incorporates

⁵⁹ Weckend, S. et al. "End-of-Life Management: Solar Photovoltaic Panels." International Renewable Energy Agency. June 2016.

⁶⁰ Hurdle, J. "As Millions of Solar Panels Age Out, Recyclers Hope to Cash In." *Yale Environment* 360. February 2023.

<https://e360.yale.edu/features/solar-energy-panels-recycling#:~:text=The%20area%20covered%20by%20solar,regulatory%20analyst%20at%20the%20lab>

⁶¹ Weckend, S. et al. "End-of-Life Management: Solar Photovoltaic Panels." International Renewable Energy Agency. June 2016.

⁶² "National Overview: Facts and Figures on Materials, Wastes, and Recycling." *Environmental Protection Agency*. December 2025.

<https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials>

⁶³ Christofell, T. et al. "Recycling Wind Energy Systems in the United States." National Laboratory of the Rockies, January 2025.

⁶⁴ "Solid Waste/Byproducts of Gasification: Background." National Energy Technology Laboratory.

<https://www.netl.doe.gov/research/Coal/energy-systems/gasification/gasifiedia/solid-waste-bg>

⁶⁵ Mirletz, H., Hieslmair, H., Ovaitt, S., Curtis, T. L., & Barnes, T. M. "Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization." *Nature*. October 2023. <https://www.nature.com/articles/s41567-023-02230-0>

recycling.⁶⁶ Following this development, a solar recycling facility in North Carolina operated by SPR announced plans to expand its capacity to handle 1.5 million panels annually.⁶⁷ Additionally, in January 2025, SPR⁶⁸ and the Solar Energy Industries Association established a 6-month pilot in Mecklenburg County to test and refine residential solar panel recycling drop-off sites and processes. The results of that pilot have not yet been shared publicly.

The average solar panel is, by weight, 76-89% glass, 4-10% plastic, 6-8% aluminum, 0-5% silicon, and 1% other metals.⁶⁹ The recycling process seeks to recover and make useful as many of these materials as possible. In 2022, it cost \$15-\$45 per panel to recycle vs. \$1-\$5 per panel to landfill,⁷⁰ though the

price of recycling specifically has declined by about 43% since 2024.⁷¹ Process-wise, panel recycling generally requires mechanical removal and separation of frames, electronics, adhesives, and glass, followed by using electricity, heat, or chemicals to separate out the silicon, plastics, and metals from the remaining layered panel materials.⁷²

Depending on the exact method used, recycling techniques can recover at most 100% of the glass, 90% of the metals, whole silicon wafers, and most of the plastics and polymers.⁷³ Each method uses various techniques and chemistries and may vary in cost and energy intensity as well, so recyclers must choose the method that works best to optimize materials recovery.

A look at historical global PV recycling trends hints at the future possibilities of the practice in our country and sheds light on the current economy for recycling. Europe installed MW-scale volumes of PV years before the U.S. In 2007, a public-private partnership between the European Union (EU) and the solar industry set up a voluntary collection and recycling system called

⁶⁶ "Utility-Scale Solar Project Decommissioning Program." *NC Department of Environmental Quality*. 2025.

<https://www.deq.nc.gov/about/divisions/waste-management/utility-scale-solar-project-decommissioning-program>

⁶⁷ Pickerel, K. "SPR expands solar panel recycling capacity at North Carolina facility." *Solar Power World*. September 4, 2025.

[https://www.solarpowerworldonline.com/2025/09/spr-expands-solar-panel-recycling-capacity-at-north-carolina-facility/#:~:text=SPR%20\(SolarPanelRecycling.com\)%20is%20adding%20a%20new%20processing,capacity%20at%20SPR's%20Texas%20and%20Georgia%20facilities.](https://www.solarpowerworldonline.com/2025/09/spr-expands-solar-panel-recycling-capacity-at-north-carolina-facility/#:~:text=SPR%20(SolarPanelRecycling.com)%20is%20adding%20a%20new%20processing,capacity%20at%20SPR's%20Texas%20and%20Georgia%20facilities.)

⁶⁸ "Home." SPR. 2026.

<https://solarpanelrecycling.com/>

⁶⁹ Powell, G. "Solar Panel Recycling: Demand, Technology & Supply Chain." *Presentation to SWANA North Carolina Chapter*. July 23, 2025.

⁷⁰ "Solar Energy Technologies Office Photovoltaics End-of-Life Action Plan." *U.S. Department of Energy*. March 2022.

⁷¹ Powell, G. "Solar Panel Recycling."

⁷² "Solar Panel Recycling." *U.S. Environmental Protection Agency*.

<https://www.epa.gov/hw/solar-panel-recycling>

⁷³ Preet, S. "A comprehensive review on the recycling technology of silicon-based photovoltaic solar panels: Challenges and future outlook." *Journal of Cleaner Production*. April 2024.

PV CYCLE. This arrangement was later made mandatory under the EU's Waste from Electrical and Electronic Equipment (WEEE) directive, a program for waste electrical and electronic equipment.⁷⁴ 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 77,000 tons between 2010 and 2022.⁷⁵

In 2012, the WEEE Directive added the end-of-life collection and recycling of PV panels to its scope.⁷⁶ 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 mandated that 85% of PV products "put in the market" in Europe are recovered and 80% are prepared for reuse and recycling.

⁷⁴ "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment." *Official Journal of the European Union*. July 2012.

⁷⁵ "Annual Report 2022." *PV Cycle*. 2015.

⁷⁶ "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment." *Official Journal of the European Union*. July 2012.

Currently, the global solar panel recycling market is valued at about \$365 million, with expected growth to about \$450 million by 2026 and \$1.5 billion by 2034; in the U.S., that market size is around \$33 million and is expected to grow to \$90 million by 2030.^{77,78}

The success of PV panel collection and recycling programs in Europe offers a promising model for the future of PV recycling in the U.S. In mid-2016, the U.S. Solar Energy Industries Association (SEIA) established the National PV Recycling Program, a network of recycling and refurbishment providers that offer end-of-life management services for solar and storage installers, project and system owners, developers, distributors, and other stakeholders. SPR is a partner in this initiative, and there are four collection sites across North Carolina.⁷⁹ The program aggregates services from recycling vendors and PV manufacturers, making it easier for consumers to identify cost-effective and environmentally responsible end-of-life solutions for PV products. In addition, the program provides an online portal with guidance on how to responsibly repair, refurbish, resell, and recycle PV modules, inverters, and other system components.

⁷⁷ "Solar Panel Recycling Market Size, Share, and Industry Analysis." *Fortune Business Insights*.

⁷⁸ "United States Solar Panel Recycling Industry - Market Trends," Inkwood Research.

⁷⁹ "Circular Economy." *SEIA*. 2026. <https://seia.org/initiatives/circular-economy/>

To further strengthen its recycling efforts, SEIA launched SolarRecycle.org in late 2025 to enhance the long-term sustainability of the solar and storage industries and to connect industry leaders with recycling partners.⁸⁰ The platform offers information on recycling best practices and solar industry standards, as well as a curated collection of resources related to solar equipment safety and environmental health. These resources include the North Carolina Clean Energy Technology Center's solar decommissioning policy snapshot publication, which provides annual legislative updates on solar decommissioning and recycling, including a comprehensive review of existing state-by-state decommissioning and financial assurance policies.⁸¹

If not recycled, solar panels are sent to a landfill, where they may be treated as hazardous waste. RCRA establishes criteria that separate waste into hazardous (not accepted at ordinary landfills) and solid waste (generally accepted at ordinary landfills) 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

⁸⁰ "Solar and Storage Industry Launches New Online Resource to Enhance Solar Recycling, Support Long-Term Sustainability." *SEIA*. October 2025.

<https://seia.org/news/solar-and-storage-industry-launches-recycling-resource/>

⁸¹ "Recent Publications." *DSIRE Insight*. 2026.

<https://www.dsireinsight.com/publications>

(TCLP) test. This EPA test is designed to simulate landfill disposal and determine the risk of hazardous substances leaching out of the landfill.^{82,83,84} Multiple sources report that most modern PV panels, both crystalline silicon and CdTe panels, pass the TCLP test.^{85,86} Some studies found that some older (1990s) crystalline silicon panels, and perhaps some newer crystalline silicon panels (specifics are not given about the vintage of panels tested) do not pass the lead (Pb) leachate limits in the TCLP test.^{87,88} As of 2022, 20% of solar panels are using lead-free solder; lead and silver each constitute less than 0.1% by

⁸² "40 C.F.R. §261.10. Identifying the Characteristics of Hazardous Waste and for Listing Hazardous Waste." *Code of Federal Regulations*. November 2016.

<http://www.ecfr.gov/cgi-bin/text-idx?SID=ce0006d66da40146b490084ca2816143&mc=true&nde=pt40.26.261&rgn=div5#sp40.28.261.b>

⁸³ "40 C.F.R. §261.24 Toxicity Characteristic." *Code of Federal Regulations*. November 2016.

http://www.ecfr.gov/cgi-bin/text-idx?SID=ce0006d66da40146b490084ca2816143&mc=true&nde=pt40.26.261&rgn=div5#se40.28.261_124

⁸⁴ Weckend, S. et al. "End-of-Life Management: Solar Photovoltaic Panels." *International Renewable Energy Agency*. June 2016.

⁸⁵ TLCP test results from third-party laboratories for REC, Jinko, and Canadian Solar silicon-based panels. Provided by PV panel manufacturers directly or indirectly to authors.

⁸⁶ "Introduction to Solar Panel Recycling." *Sinovoltaics*. March 2014.

<http://sinovoltaics.com/solar-basics/introduction-to-solar-panel-recycling/>

⁸⁷ Fthenakis, V. "Regulations of Photovoltaic Module Disposal and Recycling." *Brookhaven National Laboratory*. January 2001.

⁸⁸ Sinha, P. et al. "Evaluation of Potential Health and Environmental Impacts from End-of-Life Disposal of Photovoltaics." *Photovoltaics*. 2014.

weight of the modules, and other toxic metals are generally not detected.⁸⁹

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 18 hours, the fluid is tested for 40 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.⁹⁰ Additionally, research in Japan has found no detectable Cd leaching from cracked CdTe panels when exposed to simulated acid rain.⁹¹

While a cautious approach toward the potential for negative environmental and 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 outweigh 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.^{92,93,94}

1.2.4 Non-Panel System Components

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. Both traditional racking systems and innovative materials for racking contain

⁸⁹ Li, F. *et al.* “A review of toxicity assessment procedures of solar photovoltaic modules.” *Waste Management*. February 2024.

⁹⁰ Sinha, P. and Wade, A. “Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of PV Module Field Breakage.” *First Solar*. October 2015.

⁹¹ Matsuno, Y. “Environmental Risk Assessment of CdTe PV Systems to be considered under Catastrophic Events in Japan.” *First Solar*. December 2013.

⁹² “Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project” *RBI Solar*. June 2016.

⁹³ “Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project.” *Birdseye Renewables*. May 2015.

⁹⁴ “Decommissioning Plan submitted to Catawba County associated with permitting of a 5MW solar project.” *Cypress Creek Renewables*. September 2016.

no harmful chemicals and are extremely environmentally stable.⁹⁵

The inverters that make the solar generated electricity ready to send to the grid have weatherproof 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 similar to the cooling system in a computer. Many inverters today are also RoHS compliant. The only known health and safety concerns with inverters are voltage and temperature, which can be mitigated with proper installation and maintenance.⁹⁶

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

⁹⁵ Carrera, L. A. I. *et al.* "Advances in Mounting Structures for Photovoltaic Systems: Sustainable Materials and Efficient Design." *Technologies*. 2025.

⁹⁶ Erber, A. *et al.* "Assessment of Personal Safety Concerns of Plug and Play Photovoltaic Inverters using a Black Box Approach and Laboratory Measurements." *Solar RLL*. 2025.

polychlorinated biphenyls (PCBs).⁹⁷ Transformers 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.

Some high voltage transformers, switchgear, and circuit breakers contain sulfur hexafluoride (SF₆) gas to extinguish electrical arcs when a circuit breaker opens or to act as an insulating medium when electrical components are placed close together. SF₆ is widely used in high voltage equipment in the electric power industry, and is not specific to the electrical equipment at a solar installation. In its normal state, SF₆ is non-toxic, non-flammable, and chemically stable. Because it is a potent greenhouse gas with a global warming potential of 23,500 times that of CO₂,⁹⁸ its use is regulated across the country.⁹⁹

⁹⁷ Tiwari, R. *et al.* "Hazardous effects of waste transformer oil and its prevention: a review." *Next Sustainability*. 2024.

⁹⁸ "Sulfur Hexafluoride (SF₆) Basics." *US Environmental Protection Agency*. April 1, 2024. <https://www.epa.gov/eps-partnership/sulfur-hexafluoride-sf6-basics>

⁹⁹ "State and Regional Regulations Related to SF₆ Emissions from Electric Transmission and Distribution." *US Environmental Protection Agency*. December 12, 2025. <https://www.epa.gov/eps-partnership/state-and-regional-regulations-related-sf6-emissions-electric-transmission-and>

As of 2026, there are 35 utility-scale battery storage projects in North Carolina, with a total capacity of 290 MW.¹⁰⁰ Lithium-ion batteries currently dominate the North Carolina utility-scale battery market. While they are generally safe to use, at the end of their life, these batteries must be disposed of or recycled properly and in accordance with a recently enacted North Carolina law prohibiting disposal of lithium-ion batteries in landfills¹⁰¹ and U.S. Occupational Safety and Health Administration (OSHA) standards.¹⁰²

1.3 Operations and Maintenance

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 regularly. Some system owners may choose to wash panels as often as once a year to increase production, but most in North Carolina do not regularly wash any PV panels. Dirt buildup over time may justify panel washing a few times over the panels' lifetime; however, nothing more than water and a soft cloth or brush are required for this activity.

¹⁰⁰ "Battery Storage Projects in North Carolina." *Cleanview*. January 2026.

¹⁰¹ North Carolina General Statutes, Chapter 130 Public Health, §130A-309.10.(f).

¹⁰² "Lithium-ion Battery Safety." *Occupational Safety and Health Administration*. 2024.

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 manage vegetation at North Carolina solar facilities, including planting low-growing species, applying herbicides, weed-eating, mowing, and grazing sheep. Most sites rely on monthly mowing with sickle mowers that fit under the panels, while others use sheep grazing to reduce maintenance effort and provide high-quality lamb meat.¹⁰³



In addition to mowing and weed eating, solar facilities often use some herbicides. Solar facility owners 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 the exterior vegetative buffer, on interior dirt roads, and near the panel support posts. Also, unlike many row

¹⁰³ "Home." *Sun-Raised Farms*. 2020. <https://www.sunraisedfarms.com/>

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 North Carolina generally use significantly fewer herbicides per acre than most commercial agriculture or lawn maintenance services.

In addition, battery energy storage systems require meticulous operations and maintenance support to ensure they

remain functional and safe. Dedicated and expert O&M staff that monitor energy storage sites can respond to issues quickly and keep the site safe for workers and the surrounding community.¹⁰⁴

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 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 by a solar installation.

¹⁰⁴ Williams, J. "The truth about large-scale battery storage O&M." *Energy Storage News*. June 18, 2025. <https://www.energy-storage.news/the-truth-about-large-scale-battery-storage-om/>

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.¹⁰⁵ 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 1 mG or 0.1 μT , with about 1% of the population with an average exposure exceeding 0.4 μT (or 4 mG).¹⁰⁶ A review of epidemiological studies on the health impacts of electromagnetic fields from 2000 to 2021 shows that while some studies find a correlation between EMF exposure and cancer, others find no such correlation.¹⁰⁷

These epidemiological studies, which found an association but not a causal

¹⁰⁵ "EMF: Electric and Magnetic Fields Associated with Electric Power: Questions and Answers." *National Institute of Environmental Health Sciences*. June 2002.

¹⁰⁶ "Electromagnetic Fields and Public Health: Exposure to Extremely Low Frequency Fields." *World Health Organization*. June 2007.

¹⁰⁷ Maffei, M. E. "Magnetic Fields and Cancer: Epidemiology, Cellular Biology, and Theranostics." *Int. J. Mol. Sci.* 2022.

relationship, led the World Health Organization's International Agency for Research on Cancer (IARC) to classify extremely low frequency (ELF) magnetic fields—electromagnetic radiation with frequencies ranging from 1 Hz to 300 Hz¹⁰⁸—as "possibly carcinogenic to humans." Coffee also has this classification. This classification means there is limited evidence, but not enough evidence to designate it 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

¹⁰⁸ "Extremely Low Frequency (ELF) Radiation." *Occupational Safety and Health Administration*. 2026.

[https://www.osha.gov/elf-radiation#:~:text=Extremely%20low%20frequency%20\(ELF\)%20fields,electrical%20wiring%2C%20and%20electrical%20equipment.](https://www.osha.gov/elf-radiation#:~:text=Extremely%20low%20frequency%20(ELF)%20fields,electrical%20wiring%2C%20and%20electrical%20equipment.)

indicates that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects.”¹⁰⁹

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.¹¹⁰ 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. This 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 produces 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.¹¹¹ 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.

¹⁰⁹ “Possible Health Effects of Exposure to Residential Electric and Magnetic Fields.” *National Research Council*. 1997. <https://www.nationalacademies.org/publications/5155>

¹¹⁰ “Electromagnetic Fields and Public Health: Exposure to Extremely Low Frequency Fields.” *World Health Organization*. June 2007.

¹¹¹ “Electromagnetic Fields and Public Health: Static Electric and Magnetic Fields.” *World Health Organization*. March 2006.

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.¹¹² As stated above, the average exposure to magnetic fields in the U.S. is estimated to be around 1 mG or 0.1 μ T but can vary considerably depending on a person’s exposure to EMF from electrical devices and wiring.¹¹³ When comparing exposure to utility-scale solar facilities, including the solar PV panels, inverters, and other electrical components, the EMF exposure from the magnetic fields is extremely low. It can be compared to that of common household appliances, building wiring, and transmission lines. Other commonly used technologies, such as cell phones and microwaves, have higher frequencies.¹¹⁴

The strength of these magnetic fields diminishes 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. For example, a common vacuum can produce a magnetic field of 300 mG at 6 inches, which drops to 2 mG at 3 feet.¹¹⁵ Moreover, unless you are inside 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 can be considered “indistinguishable” from surrounding levels.¹¹⁶

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.^{117,118} 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 9

¹¹² Sheppard, A. “Health Issues Related to the Static and Power-Frequency Electric and Magnetic Fields (EMFs) of the Soitec Solar Energy Farms.” April 2014.

¹¹³ “Study of Acoustic and EMF Levels from Solar Photovoltaic Projects.” *Massachusetts Clean Energy Center*. December 2012.

¹¹⁴ “Questions & Answers Ground-Mounted Solar Photovoltaic Systems.” Massachusetts Department of Energy Resources, Massachusetts Department of Environmental Protection, and *Massachusetts Clean Energy Center*, June 2015.

¹¹⁵ *Ibid.*

¹¹⁶ “Electric and Magnetic Fields Associated with the Use of Electric Power: Questions and Answers.” *National Institute of Environmental Health Sciences*. June 2002.

¹¹⁷ Tell, R. A. *et al.* “Electromagnetic Fields Associated with Commercial Solar Photovoltaic Electric Power Generating Facilities.” *Journal of Occupational and Environmental Hygiene*. 2015.

¹¹⁸ “Questions & Answers: Ground-Mounted Solar Photovoltaic Systems.” *Massachusetts Department of Energy Resources, Massachusetts Department of Environmental Protection, & Massachusetts Clean Energy Center*. June 2015.

feet from the residential inverters and 150 feet from the utility-scale inverters.¹¹⁹ 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.¹²⁰ 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 a 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 the solar facility's fence is less than 1/1,000 of the level at which manufacturers test for ELF EMF interference, which is 1,000 mG.¹²¹ 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

¹¹⁹ Ibid.

¹²⁰ Ibid.

¹²¹ "EMFs and medical devices." *EMFS*. 2026. www.emfs.info/effects/medical-devices/

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.¹²²

EMF strength from battery energy storage sites is so small as to be negligible (on the order of hundreds of mG), is a fraction of the Earth's baseline magnetic field, and is well below most exposure limits.¹²³

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.¹²⁴

Another electrical hazard is an arc flash, which is an explosion of energy that can

¹²² Ibid.

¹²³ "Windham Energy Center Battery Energy Storage System: Report on Electric and Magnetic Fields." *Exponent, Inc.* September 2024.

¹²⁴ McCluer, D. "Electrical Construction & Maintenance: NFPA 70E's Approach to Considering DC Hazards." September 2013. <http://ecmweb.com/safety/nfpa-70e-s-approach-considering-dc-hazards>

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 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 6-foot chain-link fence with three strands of barbed wire or an 8-foot fence, both with adequate hazard warning signs.

As with any electrical equipment, there are electric shock and arc flash hazards, as well as chemical burn hazards, associated with the operation of lithium-ion storage batteries that must be carefully protected against.^{125,126}

¹²⁵ Coache, C. "A Better Understanding of NFPA 70E: Fire is not the Only Battery Safety Issue." *NFPA*. May 2024.
<https://www.nfpa.org/news-blogs-and-articles/blogs/2024/05/10/fire-is-not-the-only-battery-safety-issue>

¹²⁶ Rosewater, D. "Reducing Risk When Performing Energized Work on Batteries." *IEEE IAS Electrical Safety Workshop*. 2023.

4. Fire Safety

The possibility of fires resulting from or intensified by PV systems may trigger concern among the 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 encapsulants surrounding the PV cells, polymer backsheets (framed panels only), plastic junction boxes on the rear of the 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.

Even though solar panels are not particularly flammable and heat from a small flame is inadequate to ignite a PV panel, heat from a more intense fire or energy from an electrical fault can ignite a PV panel.¹²⁷ Most incidents are primarily driven by technical failures in the DC wiring, such as electrical arcing caused by faulty connectors, mismatched components, or compromised junction boxes. While

¹²⁷ Yang, H. *et al.* "Experimental Studies on the Flammability and Fire Hazards of Photovoltaic Modules," *Materials*. July 2015.

solar modules are functionally stable, external stressors such as shading or micro-cracks can create “hot spots” in modules that significantly increase the temperature of a specific area on the panel, potentially igniting nearby flammable material. When combined with environmental factors such as rodents chewing through cables and wear from weather conditions, these electrical and heat-based stressors represent the source of fire risk rather than the panels themselves.¹²⁸

It is estimated that there are less than 0.0289 fires per MW of installed solar panels, so for North Carolina’s 9.7 GW, that’s a potential of around 280 fires.¹²⁹ While this may seem like a lot, there were over 4,500 wildfires in 2024 in North Carolina, not including thousands of urban fires.¹³⁰ This can be mitigated through proper wiring and electrical safety, as with any electrical equipment. While it is possible for electrical faults in PV systems on homes or commercial buildings to start a fire, this is extremely rare.¹³¹ Most of the documented events where PV started a fire resulted in only

¹²⁸ Olasunkanmi, K. G., Adeniyi, A.S., and Adeyinka, A.A, "Summaries of Causes, Effects and Prevention of Solar Electric Fire Incidents." *International Journal of Engineering and Applied Physics*. January 2023.

¹²⁹ Ong, N. A. F. M. N. "Fault Tree Analysis of Fires on Rooftops with Photovoltaic Systems." *Journal of Building Engineering*, 46, 2022.

¹³⁰ "Wildfires by State, 2024." Insurance Information Institute.

¹³¹ Paiss, M. "Tech Surveillance: PV Safety & Code Developments." *Cooperative Research Network*. October 2014.

minor property damage. 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 hazards 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. Ventilating the roof helps firefighters extinguish the fire more effectively. However, the placement of rooftop PV panels may interfere with ventilating the roof by limiting access to desired venting locations.

The 2018 North Carolina building codes require solar panels to be installed in accordance with regulations that minimize fire risk, minimize obstructions to pathways and rooftops, and define certain setback distances from property lines.¹³² Furthermore, 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

¹³² 2018 North Carolina State Building Code: Fire Prevention Code. Section 605.11 Solar photovoltaic power systems.

proper firefighter training, system design, and installation. Numerous organizations have studied firefighter safety related to PV and 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 Firefighters,” features rich video content and simulated environments so firefighters can practice the knowledge they’ve learned:
www.iaff.org/pvsafetytraining
- “How to More Safely Integrate Energy Storage Systems (ESS) and Solar Photovoltaic (PV) Systems into Your Facility and Community,” National Fire Protection Association¹³³
- “A Guide to Fire Safety with Solar Systems,” U.S. Department of Energy¹³⁴

¹³³ “How to More Safely Integrate Energy Storage Systems (ESS) and Solar Photovoltaic (PV) Systems into Your Facility and Community.” *National Fire Protection Association*. 2024.
<https://www.nfpa.org/videos/safer-integration-of-ess-and-pv-systems>

¹³⁴ “A Guide to Fire Safety with Solar Systems.” *U.S. Department of Energy*. 2026.

- “Solar Farm Safety,” National Wildlife Coordinating Group¹³⁵
- “Photovoltaics and Firefighters’ Operations—Best Practices in Selected Countries,” International Energy Agency¹³⁶

A core priority in operational practices for lithium-ion-based battery energy storage systems is fire safety due to the flammable and potentially reactive properties of lithium. There is extensive research on how to manage and mitigate fire risk and extensive regulations and codes to ensure operational safety.¹³⁷



<https://www.energy.gov/eere/solar/guide-fire-safety-solar-systems>

¹³⁵ “Solar Farm Safety.” *National Wildfire Coordinating Group*. July 2025.

<https://www.nwccg.gov/6mfs/misc-fireline-hazards/solar-farm-safety>

¹³⁶ “Photovoltaics and Firefighters’ Operations: Best Practices in Selected Countries.” *International Energy Agency*. April 2017.

¹³⁷ “Battery Energy Storage Systems: Main Considerations for Safe Installation and Incident Response. Sustainable Management of Electronics and Batteries.” *U.S. Environmental Protection Agency*. August 2025.

<https://www.epa.gov/electronics-batteries-management/battery-energy-storage-systems-main-considerations-safe>

Conclusion

The purpose of this paper is to address and alleviate concerns of public health and safety for utility-scale solar PV projects and battery energy storage systems. Concerns of public health and safety were divided and discussed in the four following sections: (1) Hazardous Materials, (2) Electromagnetic Fields (EMF), (3) Electric Shock and Arc Flash Hazards, and (4) Fire Safety. 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.