HEALTH AND SAFETY ASSESSMENT REPORT

Purdy Solar
80 MW_{AC} Photovoltaic Facility with
4-hour Battery Energy Storage
Greensville County, VA

ABSTRACT

This is an assessment of the potential health and safety impacts of the proposed 80 MW_{AC} Purdy Solar photovoltaic facility with battery energy storage (BES) in Greensville County, VA. Considering the project design and location, the assessment evaluates the potential positive and negative impacts of the project on public health and safety. Most of the project area will be covered by solar equipment, which produces valuable electricity without producing any air, water, or soil emissions. The primary health and safety risk of the system equipment is toxicity, which is considered in detail in this assessment. The battery equipment will occupy a tiny portion of the site's footprint and will provide many benefits to the electric grid. The primary health and safety risk of the battery equipment is fire, which is minimized by advanced battery technologies, 24/7 monitoring and fire suppression systems, new battery regulations and the long distance between the equipment and the public. The conclusion of the assessment is that the Purdy Solar facility will not create negative health and safety impacts. The clean electricity the project will produce will reduce the burning of fossil fuels, which will reduce pollution and provide hundreds of millions of dollars' worth of local public health benefits as a result, based on U.S. Environmental Protection Agency estimates.

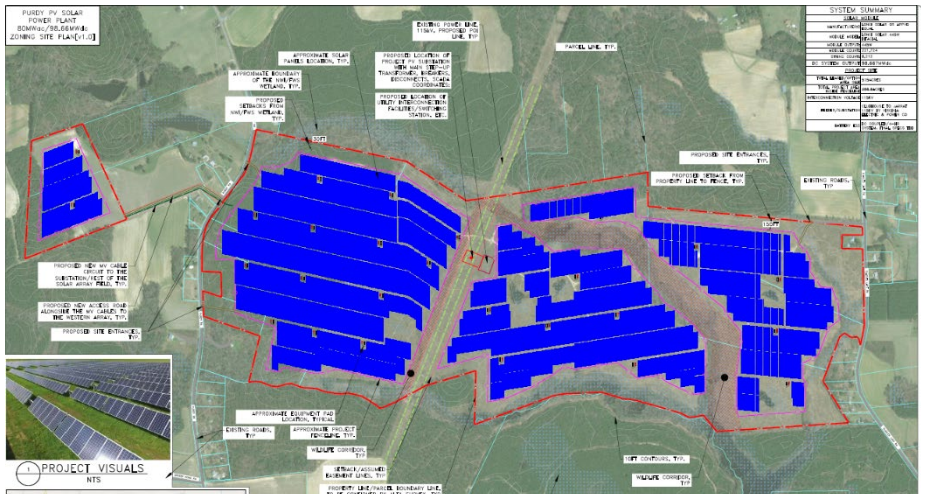
Tommy Cleveland, PE
Consulting Engineer
Solar Health and Safety Expert

January 18, 2022

Health & Safety Assessment Report

Purdy Solar (with BES) – Greensville County, VA

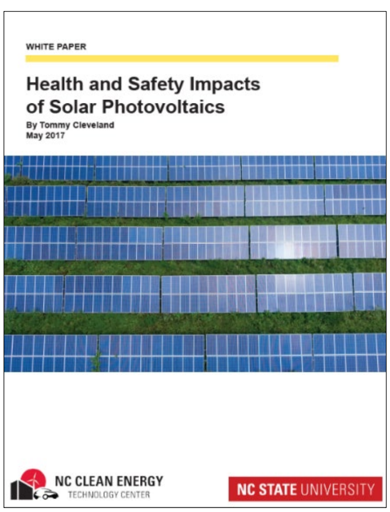
Project Overview:



- **Project Name:** Purdy Solar
- **Developer**: Palladium Energy with Renewable Energy Services
- **Capacity**: 80 MW_{AC} (~99 MW_{DC})
- **Project Area**: ~550 acres, ~387 acres inside the fence
- **Solar Panels**: bi-facial crystalline silicon, LONGi Solar 540W or equivalent
- **Structure**: single-axis trackers (north-south rows, 60° E to 60° W)
- **Inverters**: central station type (~2-5 MW each)
- **Battery Energy Storage:** up to 80 MW and 320 MWh (assuming 4-hour duration), DC-coupled
- **Battery type:** lithium-ion batteries, specifically Lithium Iron Phosphate (LFP) chemistry
- **Point of Interconnection**: Virginia Electric & Power Co. Clubhouse-Jarrett 115 kV transmission line near center of project
- **Interconnection Equipment**: Virginia Electric & Power Co. switchyard and 34.5kV/115kV project substation

Report Author

The author of this report is **Tommy Cleveland, PE**, a consulting engineer licensed as a professional engineer in NC since 2007 and licensed in VA since 2021. Mr. Cleveland graduated from North Carolina State University with undergraduate and master's degrees in mechanical engineering, where he focused on energy. His solar career started with his master's thesis, which led to working over 12 years at the North Carolina Clean Energy Technology Center at NC State University. While at the university Tommy worked on nearly every aspect of solar energy; from teaching, to testing equipment, to system research & development, to leading a statewide stakeholder group in the development of a template solar ordinance. During his time at NC State, North Carolina installed more photovoltaic (PV) capacity than any state other than California, mostly in the form of 3-5 MW_{AC} utility-scale solar facilities covering around 40 acres each. Utility-scale solar was new in the US and unfamiliar to the hundreds of communities around the state where the systems were proposed, and many of those communities had questions about the technology and its potential to harm public health or the environment in their community. Many of those questions found their way to Mr. Cleveland and he expanded his already broad knowledge of photovoltaics to research and find answers to the questions being asked. Over time he became an expert on the potential health and safety impacts of photovoltaics and was the lead author of the 2017 NC State white paper on the topic. Since mid-2017 Mr. Cleveland has worked as a solar engineer at an energy engineering firm conducting interconnection commissioning of utility-scale solar and battery facilities for utilities in North and South Carolina. In this role Mr. Cleveland was the engineer responsible for (interconnection) commissioning over 60 solar sites and 4 battery sites.



Executive Summary

This report assesses the potential health and safety impacts of the proposed Purdy Solar 80 MW_{AC} solar photovoltaic with battery energy storage project. The Purdy Solar facility, located in Greensville County, Virginia, will install crystalline silicon solar panels on single-axis tracking racks that slowly rotate each row of panels to follow the sun across the sky. Large central station inverters will convert the DC solar electricity generated by the solar panels into grid-synced AC electricity. Containerized battery systems, capable of storing and discharging energy, will be spread throughout the array, co-located and connected to the DC side of the inverters. Transformers will boost the voltage for connection to an onsite substation that connects to a transmission power line running through the project.

Photovoltaic (PV) panels are not new. They have been used and studied for over 40 years and are well understood by the scientific community. Utility-scale solar facilities are newer, but they too have been installed and studied for over a decade, and scientists also have a clear understanding of their function and impacts.

Utility-scale battery energy storage systems are newer still but have been maturing very quickly in the last few years. Purdy Solar will use a leading lithium-ion battery technology with a much lower risk of fire and fire-related impacts than other leading lithium-ion chemistries.

Photovoltaic systems produce emission-free electricity. This replaces electricity production from fossil fuel power plants that produce harmful emissions. The health benefits of clean solar electricity are hard to put a dollar figure on, but the EPA's best attempt at doing just that puts the value in the mid-Atlantic US between 3.1 and 7.0 cents per kWh produced. Even at the bottom end of this range, this equates to approximately $5 million of public health benefit per year for the Purdy Solar project, and over $150 million in 30 years.

The only identifiable risks to health and safety of the PV aspects of the Purdy Solar project are not unique to solar but exist for any source or use of electricity. These are electric shock, arc flash, and fire. Due to world-class safety regulations in the U.S. and an experienced solar industry, these risks are extremely low, and the secure and isolated nature of ground-mounted PV facilities, including Purdy Solar, results in minimal risk to the general public.

Common concerns about toxicity and EMF from solar facilities are understandable, but the operating characteristics and materials present in the equipment means that neither toxicity nor EMF pose a material risk to public health or safety. Research and experience regarding heat island effect and solar glare shows that, like other utility-scale PV projects, the Purdy Solar project will not create either of these potential impacts. The single-axis trackers at Purdy Solar that will keep the panels facing in the direction of the sun minimizes the potential for the project to create any glare.

Modern US battery codes and standards minimize the risk of fire, effectively remove the risk of explosion, and the project will use the safest of the common lithium-ion battery chemistries reducing the risk even further. A battery fire would damage equipment but due to the distance between the batteries and the public, a fire would not negatively impact public health or safety.

Based on my knowledge of engineering and science, personal experience with PV and battery technology, review of academic research, and review of project materials provided by Renewable Energy Services and Palladium Energy my findings and opinions are summarized as follows:

- The development and operation of the Purdy Solar PV and battery facility will not result in any environmental contamination or negative impacts to public health or safety.
- The Purdy Solar facility will not increase the temperature of the area surrounding the site.
- The Purdy Solar facility is not expected to create any glare hazards or other negative glare impacts.

Introduction

Purpose:

This report assesses the potential health and safety impacts of the proposed Purdy Solar (“Purdy”) 80 MW_{AC} solar with battery energy storage (BES) project. It also seeks to educate readers on the health and safety impacts of photovoltaic and battery energy storage systems using accurate scientific sources of information, including providing resources for further reading.

Battery Assessment

FOLLOW THE BATTERY ICON FOR ASSESSMENT OF BATTERIES

System Overview: Solar with Batteries

The proposed Purdy Solar facility is a utility-scale photovoltaic generation facility with lithium-ion battery energy storage. Lithium-ion batteries are available in a variety of different chemistries, and Purdy Solar will use the lithium iron phosphate (LFP) chemistry due to its superior safety characteristics. The energy storage is in the form of containerized battery systems located at the inverter pads and connected to the PV system on the DC side of the inverters, which is referred to as “DC-coupled” batteries. DC-coupled batteries are dispersed throughout the entire site because they must be connected to each inverter. Being connected in this way allows the batteries to be charged with electricity generated by the solar panels, including excess solar energy that normally would not be used because it is above and beyond the amount of power that the inverters can convert. In general, the batteries are charged by solar during peak hours and discharged when there is little or no sun shining but grid electricity is in high demand, and it repeats this cycle daily.

Overview of Potential Impacts:

The proposed solar photovoltaic (PV) and BES system is likely to remain in operation at least 30 years, and this report considers its potential impacts in Greensville County from the start of construction onward, including decommissioning of the project and restoration of the land. This assessment considers all aspects of the project but focuses on those unique to solar with battery energy storage projects.

Potential ***Positive*** *Health and Safety Impacts:*

Every utility-scale PV project significantly reduces pollution by producing emission-free electricity that replaces electricity that otherwise would have been largely produced by burning coal and natural gas. Burning these fossil fuels for electricity production is a significant source of air, water, and soil pollution, so reducing their use is a clear public health benefit.

The US Environmental Protection Agency (EPA) conducted a study to determine how much pollution PV systems save and to estimate the public health value of the cleaner air, water, and soil they provide. These experts calculated that in the mid-Atlantic states, based on the sunshine available, the way electricity is produced, and the public health impacts of fossil fuel-fired electricity, every kilowatt-hour (kWh) of solar electricity produced provides 3.1 to 7.0 cents of public health benefit.[1] At this rate of benefit, **the Purdy Solar project will produce $5 - $11 million of public health benefits every year**, which would add up to **$150 - $335 million over the life of the project**. The public health benefits of generating pollution-free electricity with PV are very significant.

It is relatively simple to replace a small amount of grid energy with utility-scale solar energy, but as the portion of grid energy provided by solar becomes more significant it becomes increasingly challenging to integrate more solar without sacrificing reliability or power quality. Energy storage is a simple solution to overcome most of these challenges, and recent cost reductions and increased experience makes it feasible to integrate significant energy storage into solar facilities. While many types of energy storage are technically possible, battery energy storage has proven to be most practical. So, the inclusion of battery energy storage in projects like Purdy Solar improve the economics of the projects, such that some projects may not be feasible without the benefits of the batteries.

[1] US Environmental Protection Agency, Public Health Benefits-per-kWh of Energy Efficiency and Renewable Energy in the US: A Technical Report. 2nd Ed, May 2021, www.epa.gov/statelocalenergy/public-health-benefits-kwh-energy-efficiency-and-renewable-energy-united-states

The positive benefits of photovoltaics are widely understood and well documented, so this report will not address them further. Furthermore, the positive public health impacts of the Purdy Solar project significantly outweigh any health and safety risks, as described below. The ability of energy storage to facilitate increased solar energy on the grid is widely understood and well documented, but direct analysis of the positive benefits of a battery system is less common. A life cycle environmental impacts assessment of utility-scale battery energy storage in California found that when the positive and negative carbon impacts of batteries are considered that the batteries reduce the carbon footprint of the grid due to the storage's ability to storage and then release solar energy that otherwise would have gone unproduced due to curtailment.[2] Similarly, a carbon assessment of EOS zinc-based, lithium ion, and flow batteries, found that all of these battery technologies have carbon payback periods much shorter than their useful lives.[3]

Potential ***Negative*** *Health and Safety Impacts:*

All electricity generating facilities, including photovoltaics and batteries, provide some potential for negative health and safety impacts, however the Purdy project does not present negative health and safety risks to the general public due to its location or technology (photovoltaic generation with battery energy storage). The only aspect of the PV portion of the system at Purdy Solar that presents risk of physical harm is the potential for electrical shock or arc flash, which are hazards present with any electrical system and not unique to solar. There are several other aspects of PV systems that often raise public health and safety concerns, but no other aspect of PV systems poses signficant risk of negative public health or safety impacts.

Like PV systems, battery systems also produce a limited electrical shock and arc flash hazard, however unlike PV systems batteries also have the potential for toxicity, fire, and explosion hazards. While it is possible for lithium-ion batteries to catch fire, release toxic gases, and even explode, these hazards at the Purdy Solar site do not pose any risk to the general public because the battery systems are outdoors and hundreds of feet from the closest neighbor.

The major health and safety risk of the project is not due to the solar or battery technologies but is standard construction hazards for construction workers building the site, which does not pose any safety risk to the general public.

Utility-scale PV is becoming a mature, but still rapidly growing, industry. The underlying PV technologies of silicon and cadmium telluride have been studied in the laboratory and in the field for well over 30 years. So, the products, practices, regulations, and policies in the PV industry have a well-established base to build on. Also, research literature on potential negative impacts of photovoltaics goes back decades. Modern utility-scale battery energy storage is a rapidly emerging industry, largely building on the success of lithium-ion batteries in consumer products and electric vehicles. So, the products, practices, regulations, and polices in the BES industry are changing extremely rapidly, often with technology change leading policy and regulations changes. Even though there have been years of experience with batteries in laptops and phones, stationary multi-megawatt battery systems at solar facilities are still quite new. The industry is only a handful of years old, with equipment to be installed in 2022 or later much more mature than technology installed just 3 or 4 years ago. In that time, codes and standards have gone from being designed for small lead-acid battery emergency back-up power to being robust regulations built on several years of early BES experience with input from a wide array of battery stakeholders and experts. Just 3-4 years ago the battery regulations for stationary solar left system safety to the equipment manufacturers. During this "wild west" period of utility-scale BES development many valuable safety lessons were learned. See below for several recent publications on the potential health and safety impacts of battery energy storage systems.

[2] Balakrishnan, Brutsch, Jamis, et al, Environmental Impacts of Utility-Scale Battery Storage in California, 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), June 2019, www.firstsolar.com/-/media/First-Solar/Sustainability-Documents/Environmental-Impacts-of-Utility-Scale-Battery-Storage-in-California.ashx

[3] Boundless Impact Research & Analytics, EOS Climate Impact Profile, November 2020, https://eosenergystorage.com/wp-content/uploads/EOS-Impact-Profile-Final-20201124.pdf

Sources for Further Reading on Battery Impacts:

- Sandia National Lab: Grid-scale Energy Storage Hazard Analysis & Design Objectives for System, August 2020
- Energy Response Solutions, Inc.: Energy Storage System Safety: Comparing Vanadium Redox Flow and Lithium-Ion Based Systems, Aug 2017
- National Fire Protection Association (NFPA): Energy Storage Systems Safety Fact Sheet, June 2020
- New York State Energy Research and Development Authority: New York Battery Energy Storage System Guidebook for Local Governments, December 2020
- Electric Power Research Institute (EPRI): Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide, March 2019

The review and permitting process Virginia requires for utility-scale solar projects provides some certainty that the proposed project will not cause significant environmental or health impacts. The Virginia Department of Environmental Quality (DEQ) coordinates reviews from the Department of Historic Resources, the Department of Wildlife Resources, and the Department of Conservation and Recreation to ensure potential significant impacts to cultural or threatened and endangered species are avoided or mitigated. These reviews ensure the project complies with state regulations for small renewable energy projects (up to 150 MW).[4] The site is not authorized to begin construction until DEQ completes this review and provides authorization. Additionally, the project must comply with all other applicable local, state, and federal statutes and regulations, including but not limited to, strict adherence to applicable state and local erosion and sediment control/storm water management laws.

This assessment report will address all the potential health and/or safety risks of the Purdy project, including common concerns that have no potential for public health impact. Specifically, this report addresses the following possible negative impacts/concerns:

- Electrical Shock and Arc Flash
- Fire and Emergency Response
- Toxicity / Chemical
- Electromagnetic Fields (EMF)
- Heat Island Effect
- Glare

To meet the Greensville County solar ordinance, Purdy Solar will include a 150 ft setback from neighboring property lines and will be significantly screened from the ground-level view of adjacent properties by a buffer zone at least 100 feet wide containing a planted vegetative screen and/or existing vegetation or natural land forms. This is a large setback buffer compared to many solar facilities and most other land uses, and multiple rows of vegetative screening is very uncommon around existing solar facilities and many other land uses. This combination of significant setback and thick vegetative screening will separate the public from this project and minimize its impacts, including the visual/aesthetic impact of seeing the equipment.

The Greensville County solar ordinance also gives the county authority to shut down and remove the solar facility if it is declared to be unsafe by the zoning administrator or building official and not brought into compliance within fourteen days.

Before addressing each of these impact categories, this report provides an overview of utility-scale photovoltaic and battery energy storage equipment and facility construction and operations. These photos should help introduce utility-scale PV and batteries to any reader who has not toured a facility during construction or operation.

[4] Solar Permit By Rule (9VAC15-60), Chapter 60. Small Renewable Energy Projects (Solar) Permit by Rule, https://law.lis.virginia.gov/admincode/title9/agency15/chapter60/

Equipment, Construction, and Operations[5]

To understand the potential impacts of a utility-scale PV and battery system it is helpful to understand the components of the facility, as well as how a facility is constructed and maintained. The components and practices in this overview are typical of the industry and representative of the proposed Purdy Solar project. The initial site work occurs first, but the order of the other construction steps is flexible and may occur concurrently.

Initial Site Work (construction entrance/driveway, sedimentation and erosion control installation, clearing and grubbing, potentially some grading, perimeter fence, and internal roads)



Underground Work (trenching for wires from PV combiner boxes to inverters, inverter pad installation, medium voltage cables to interconnection equipment)



PV Panel Structure/Racking (driving of steel piles, installation of racking "tables", installation of PV panels)

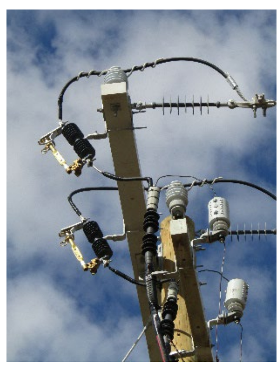


[5] Photo sources: author, ncre-usa.com, NC DEQ, blueoakenergy.com, solarbuildermag.com, hbc-inc.com, solarprofessional.com, enr.com, dynapower.com, ie-corp.com, ccrenew.com, and landiscontracting.com

Electrical Work (connection of PV module wiring, combiner boxes, inverters, batteries, transformers, interconnection facilities)






Establishment of Ground Cover (required to close out sedimentation and erosion control permit)


Operations and Maintenance (24/7 monitoring, vegetation maintenance, preventative maintenance)



Electrical Shock and Arc Flash

Figure 1. Perimeter Fence with Warning Signs

Any electricity over 50 volts presents an electrical shock hazard, including the electricity in PV and battery facilities. However, like electrical systems in buildings, the solar and battery facility must adhere to the National Electrical Code (NEC) and the equipment must be certified to the appropriate UL safety standards. Unlike buildings, members of the public are restricted from entering a utility-scale solar facility. To help ensure that only qualified people have access to the equipment, the NEC requires a secure perimeter security fence with electrical warning signs. The lack of public access coupled with the high U.S. electrical safety standards essentially eliminates the risk of electric shock for the public.

In circuits with significant available fault current there is another electrical hazard, called arc flash, which is an explosion of energy that can occur due to a short circuit. This explosive release of energy causes a flash of light and heat, creating a shockwave that can knock someone off their feet. The risk of arc flash in a solar and battery facility is no different than the risk at commercial or industrial buildings, except that solar facilities are much less accessible. Equipment with an arc flash risk require arc flash warning labels, and only trained personnel wearing the proper personal protective equipment are allowed in it. Due to the secure perimeter and the high U.S. electrical safety standards there is essentially no arc flash risk to the public.

Fire Risk and Emergency Response

Every electrical system has some risk of starting a fire, including electrical systems in residential, commercial, and industrial buildings. It is this hazard that motivated creation of the National Electrical Code over 100 years ago. Due to the high standard required by the NEC, modern electrical systems rarely start fires. Like electrical systems in buildings, ground-mounted photovoltaic systems and battery energy storage systems must also adhere to the NEC, including sections of the NEC with specific rules for PV and for batteries.

Fire Risk: Solar

In the rare case that a PV system has a fault that starts a fire there is very little combustible material present for it to ignite. The only flammable portions of PV panels are the few thin plastic layers, the plastic junction box, and the insulation on its wires. Heat from a small flame is not adequate to ignite a PV panel, but an intense fire or an electrical fault can ignite a PV panel. One real-world example illustrating the low flammability of PV panels occurred during July 2015 in an arid area of California. Three acres of grass under a utility-scale PV facility burned without igniting the panels mounted just above the grass.[6]

The most significant fire hazard at a utility-scale solar facility may be the oil in the transformers. There are medium voltage transformers dispersed throughout the site located by each inverter, and there is a large transformer in the interconnection substation. Traditionally these types of transformers have been filled with a mineral oil, which is derived from petroleum. The mineral oil is electrically insulating but flammable. The transformers are not unlike the transformers throughout every community, at shopping centers, schools, factories, neighborhoods, etc. There are best practices for how to prepare for and conduct an emergency response at a transformer. For example, see the NERC lessons learned document in the Sources for Further Reading at the end of this section.

Fire Risk: Batteries

Batteries can store a lot of energy, which makes them valuable but can also mean they have the potential to unintentionally release that energy very quickly, which can cause a fire or even lead to an explosion. The degree of fire risk varies greatly not only between battery chemistries but also between different battery systems. There have been some fires at utility-scale batteries in recent years in the US and around the world, however newer battery systems have learned from these experiences and have corrected many of problems that led to these early fires. Our understanding of battery fires and how to avoid them has rapidly increased the last few years as experience has grown from near zero to many thousands of systems. With this experience has come improved battery systems and improved codes and standards.

Generally, all utility-scale batteries are packaged in outdoor-rated containerized enclosure with a battery management system (BMS). By far the most common type of utility-scale battery is lithium-ion. While there are several different lithium-ion chemistries, all the varieties on the market today consist of cells that each contain a solid anode and cathode separated by liquid electrolyte, which is generally flammable. Many of these cells are connected into a module, several modules are connected in a rack, and several racks are connected in the containerized battery system. Each level has physical barriers and a protective battery management system.

The fire risk starts at the cell level, where if a cell faults or is abused in some way it often produces heat. It is possible for the heating to continue until the cell is generating heat more quickly than it can dissipate the heat, resulting in a rapid, accelerating rise in temperature, which is known as thermal runaway. When the cell reaches high temperatures, it vents gases that are often flammable and toxic. The heat from a single cell in thermal runaway could cause nearby cells to also go into thermal runaway, causing more heat and the potential to drive more cells into thermal runaway. However, there are early warning signs of problems before there is any smoke or fire, allowing for automatic protection systems to act early enough to avoid the worst impacts and potentially avoid thermal runaway all together. The national electrical code (NEC) requires that the battery be certified to UL 1973, the battery safety standard for stationary batteries, which includes a requirement that the battery module does not allow fire outside of the module or any explosion. The NEC also requires the battery system to be certified to UL 9540 that addresses the safety of the entire battery system.

The Purdy Solar project will use lithium iron phosphate (LFP) lithium-ion batteries, which is a lithium-ion chemistry becoming commonly used in stationary batteries. The early utility-scale BES systems nearly all used lithium manganese cobalt oxide (NMC) or lithium nickel cobalt aluminum oxide (NCA) chemistries, but now lithium iron phosphate (LFP) is used in many stationary battery systems due to its lower cost and superior safety.[7] The NMC and NCA chemistries are both susceptible to the classical thermal runaway scenario, however LFP cells are much more stable and much less susceptible to going into thermal runaway. Testing by Sandia National labs to determine the thermal runaway characteristics of the common lithium-ion chemistries found that when heated to very high temperatures the heat output from LFP cells was less than $1/1000^{th}$ the

[6] Matt Fountain. The Tribune. Fire breaks out at Topaz Solar Farm. July 2015. www.sanluisobispo.com/news/local/article39055539.html

[7] Electric Power Research Institute (EPRI), Lithium Ion Battery Energy Storage End of Life Management Infographic, April 2021. https://www.epri.com/research/products/000000003002019572

heat output of the next closest chemistry.[8] Thus, battery systems using LFP cells are at much lower risk of a significant fire or explosion.

In addition to updated equipment standards, there are new installation standards, notability the (National Fire Protection Association) NFPA 855 Standard for the Installation of Stationary Energy Storage Systems which covers the "design, construction, installation, commissioning, operation, maintenance, and decommissioning of stationary ESS." This standard addresses everything from hazard assessment to emergency response planning, and determines when large scale fire testing per UL 9540A is required. UL 9540A is the U.S.'s "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems", which was first published in late 2017 and has recently had a significant impact on the safety of battery systems. The test starts with a cell level test and only proceeds to module, unit, and installation level tests if the lower-level tests find a fire risk. The UL 9540A test for the cell level consists of attempts to cause the battery to burn or emit flammable gas. The abuse tests include driving a 2.5-inch nail through the battery, overcharging the battery to 200% of nominal charge, and short circuiting the positive and negative terminals of the battery. Any off gassing is captured and analyzed to determine the gases released, and the tests are videoed, with all of this data included in the test results.

With lithium-ion batteries there is always some risk of fire, however when built and installed in compliance with the modern US battery safety codes and standards the risk of fire is extremely small and the risk of explosion is practically zero. When the cells are LFP the risks are lowered even further. Due to the isolation of the Purdy Solar batteries from the public due to being located inside of the solar facility and proper emergency response planning and training, even a battery explosion would not impact the public. In a worst-case scenario of a large fire in a battery enclosure that destroys the entire unit, the only potential impact to the public is due to the smoke emitted by the fire. The smoke from a lithium-ion battery fire is very similar to the smoke from a fire of a similar mass of common plastics[9], which is more toxic than wood smoke and likely more toxic than the smoke from a burning building. However, at Purdy Solar the significant distance from each battery enclosure to the nearest neighbors makes the potential health impact from smoke from a battery fire insignificant.[10]

Thus, there is very little chance of a fire in the batteries at Purdy Solar, and even the worst-case situation of a fire in a single battery enclosure would not produce enough smoke for long enough to have a material impact on public health.

Emergency Response: Solar

No special equipment is required to respond to a fire incident at a utility-scale PV facility. The most important thing for first responders to know is that as long as the sun is shining on the PV panels they will produce dangerous voltage, but there is no danger in touching undamaged panels. There are multiple electrical disconnect switches in PV systems which allows problem areas to be electrically isolated quickly.

Risks of fire associated with vegetative ground cover are reduced by landscaping plans that keep this vegetation low. Local emergency responders typically have access to open locked gates and training on the electrical hazards within the site. So, they are able to safely extinguish grass fires inside of the facility, or monitor and protect the areas surrounding the facility, to ensure the fire does not spread to surrounding areas. The solar facility is remotely monitored around the clock, and responding personnel are available 24/7 for emergencies. The International Association of Fire Fighters (IAFF) provides online training on responding to fires at photovoltaic facilities at www.iaff.org/solar-pv-safety.

Emergency Response: Batteries

No special equipment is needed to respond to a battery fire. In fact, many facilities direct firefighters to not fight the battery fire at all but to allow the fire to burn itself out. In this case, the site's emergency response plan likely calls for a defensive

[8] Lamb and Jeevarajan, New developments in Battery Safety for Large-Scale Systems, MRS Bulletin, Volume 46, May 2021. https://link.springer.com/content/pdf/10.1557/s43577-021-00098-0.pdf

[9] Sandia National Laboratories, Grid-scale Energy Storage Hazard Analysis & Design Objectives for System Safety, August 2020, https://www.osti.gov/servlets/purl/1662020

[10] An example of toxic smoke impact analysis for a project using Tesla MegaPack lithium-ion battery with a church and residences approximately 200 feet from the batteries: Hazards Assessment Final Report Orni 34 LLC Battery Energy Storage System Prepared for Santa Barbara County, Nov. 2019, https://files.ceqanet.opr.ca.gov/257908-2/attachment/lD6EjpwCFrLAn_Z0Z-SNkEMFUIsW7hhYR-5owwCukaV4k_p5sk_bEIvYOC3UYKgeBtfprFm-FaYmK0eu0

firefighting approach in which firefighters may spray adjacent equipment with water to ensure the fire doesn't spread beyond a single battery enclosure. When the plan calls for actively fighting the battery, the best method is to douse the fire with water. The NFPA 855 installation standard requires that the facility create an emergency response plan and provide the plan and training to the local fire department. The appropriate first responders' actions will vary depending on the type of battery at the site, so it is vital that the facility create an emergency response plan specific to the equipment and procedures of that facility and educate the local fire departments on the equipment and the response plan. The National Fire Protection Association (NFPA) provides on-line training on PV and Energy Storage: https://catalog.nfpa.org/Energy-Storage-and-Solar-Systems-Safety-Online-Training-P20882.aspx

Sources for Further Reading on Fire and Emergency Response:

- Duke Energy: Fire Safety Guidelines for Rooftop- and Ground-Mounted Solar Photovoltaic (PV) Systems, September 2015
- North American Electric Reliability Corporation (NERC): Lessons Learned, Substation Fires: Working with First Responders, February 2019
- Sandia National Lab: Grid-scale Energy Storage Hazard Analysis & Design Objectives for System, August 2020
- Energy Storage Association (ESA), Operational Risk Management in the U.S. Energy Storage Industry: Lithium-Ion Fire and Thermal Event Safety, September 2019
- Electric Power Research Institute (EPRI): Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide, March 2019
- Electric Power Research Institute (EPRI): Proactive First Responder Engagement for Battery Energy Storage System Owners and Operators, September 2021
- Tesla: Lithium-Ion Battery Emergency Response Guide, July 2021 (Version 2.3)
- also see *Sources for Further Reading on Battery Impacts* on page 5 of this report

Toxicity (Equipment and Operations)

Toxicity is probably the most common health and safety concern about photovoltaic systems, although as detailed below the systems do not pose a material toxicity risk to the public or the environment. This report examines all possible sources of toxicity, from site construction to decommissioning at the end of the project life. The potential sources of toxicity are organized into two categories: equipment and operations and maintenance (O&M).

Toxicity: Equipment

The main equipment installed at a solar facility includes photovoltaic modules (aka solar panels or PV panels), metal structures for mounting the solar panels, and wiring to collect the electricity they produce. The other major components are inverters and transformers. Inverters are enclosed power electronic equipment that do not contain liquids and are treated like other electronic waste (e-waste) at the end of their life. Transformers contain non-toxic mineral or vegetable oil and are no different than the typical utility transformers outside of most schools and shopping centers. Solar panels have raised the most public concerns related to toxicity, so they are the only component addressed in this section on solar equipment.

Contents of PV Panels

The Purdy Solar project will use crystalline silicon PV panels from a Bloomberg Tier 1 manufacturer[11]. The PV panels are the most expensive and most important component in a solar facility, so the project owner performs industry-standard due diligence to ensure that the panels selected and delivered to the project are properly manufactured, certified, and tested.

[11] The financial information firm Bloomberg has developed a tiering system for PV module makers based on bankability that is the standard the PV industry uses to differentiate between the hundreds of manufacturers of solar modules on the market. Tier 1 is the highest of three tiers, which are determined by banks' confidence in a manufacturer's PV panels as demonstrated by their willingness to supply project financing backed only by the assets of the project. The details are described by BloombergNEF in this document: PV Module Tier 1 List Methodology https://data.bloomberglp.com/bnef/sites/4/2012/12/bnef_2012-12-03_PVModuleTiering.pdf

The diagram below shows the components of a typical silicon PV panel, including a close-up of the solar cells and the electrical connections between each cell. Over 80% of the weight of a PV panel is the tempered glass cover and the structural aluminum frame, which work together to create a strong, durable panel that outlasts its 30-year performance warranty. The encapsulation films are clear plastic lamination layers that protect the PV cells and electrical contacts from moisture for the life of the panel. These layers also maintain the panel as a single unit in the event of breakage of the tempered glass front cover, similar to the film in auto windshields that keeps them from fragmenting if the windshield shatters.

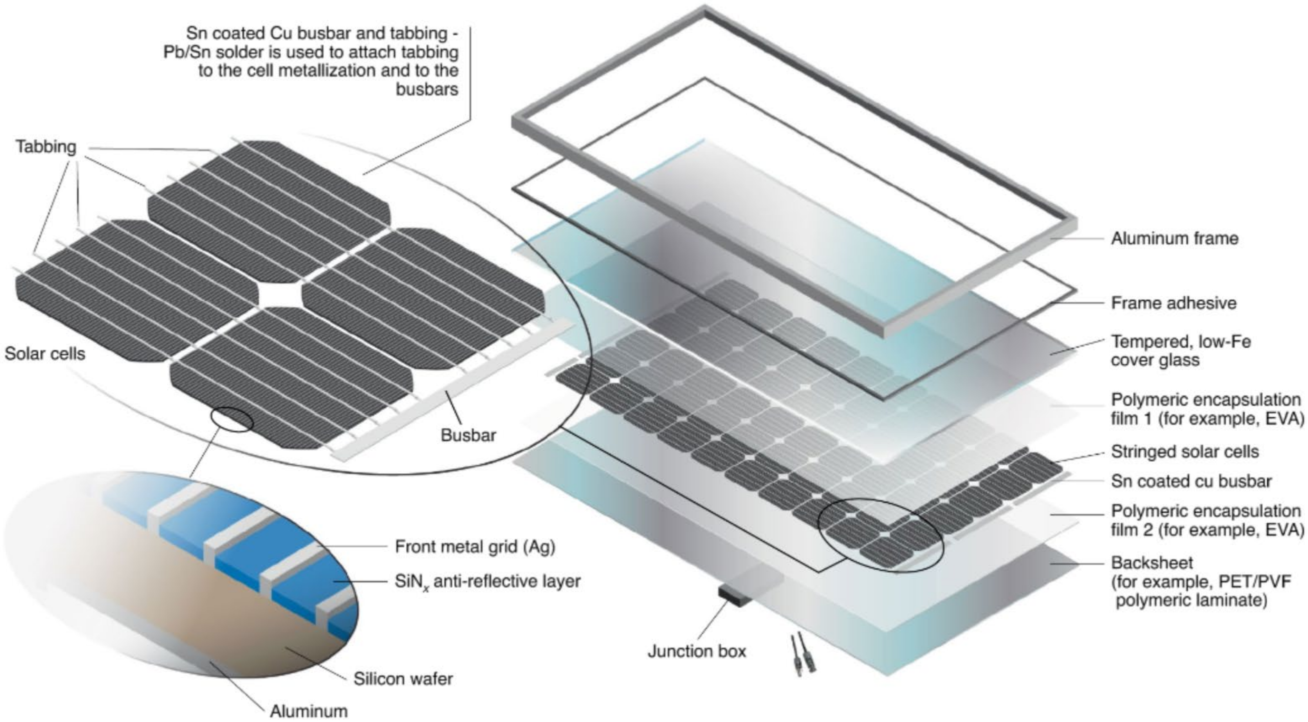


Figure 2. Contents of Framed Crystalline Silicon Panels (Source: NREL)

As can be seen in the above diagram, there are no liquids to leak from a broken panel. The plastic layers are inert. The silicon PV cells are nearly 100% silicon, which is harmless and is the second most common element in the Earth's crust. The only components of a PV panel that have any potential of toxic impact is the solder used to connect the solar cells together and to the busbars at the end of the panel, and the thin strips of silver that collect electricity from each cell. The solder, which is the same tin-lead solder standard in the electronic industry, is 36% lead. The tiny amount of silver in a panel does not create a toxicity hazard, but it does add potential recycling value.

Even though there is only a tiny amount of lead in each panel, the total amount of lead in all the PV modules in a utility-scale project adds up to a considerable amount of lead. However, these PV panels are spread out over a large area and when the amount of lead in the PV panels is compared to the amount of lead naturally occurring in the soil under the PV array it is obvious that even if all the lead somehow leached out of every module (which as explained below is impossible) the increase in total lead in the soil would be less than the naturally occurring difference between different soils. Across the US, soils naturally have between about 10 and 50 mg of lead per kg of soil, with the average being somewhere in the 20s. Across the 66 USGA survey locations in VA, the values ranged from 7.7 to 153 with an average of 27 and a median of 21.[12] For a location that naturally has 20 mg of lead per kg of soil, all the lead in all the PV modules in the facility would have the same amount of lead as just the top 2.5 inches of soil at the site![13]

[12] Smith, D.B., Cannon, W.F., Woodruff, L.G., Solano, Federico, Kilburn, J.E., and Fey, D.L., 2013, Geochemical and mineralogical data for soils of the conterminous United States: U.S. Geological Survey Data Series 801, 19 p., http://pubs.usgs.gov/ds/801/

[13] PV: 12 g of lead (per panel) per 65 ft^2 (panel footprint of 21.5 ft^2 / ground coverage ratio of 0.33) = 0.185 g of lead/ft^2
Soil: 20 mg of lead per kg of soil * 45 kg of soil per ft^3 * 2.5 inches (0.208 ft) soil depth * 65 ft^2 = 12.17 g of lead / 65 ft^2 = 0.187 g of lead/ft^2

Broken PV Panels

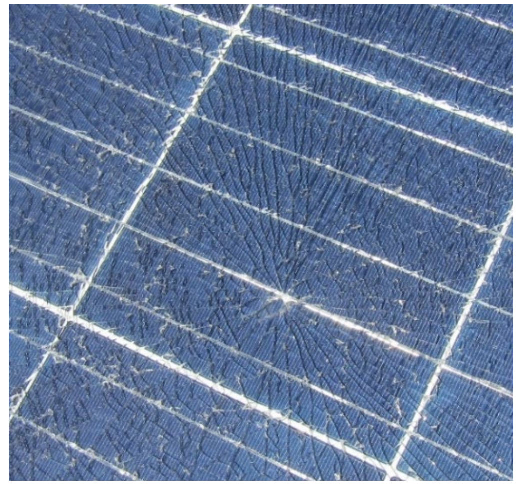


Figure 3. Close-up photo of impact point that broke the glass front of this PV panel

There is zero risk of toxicity escape from undamaged PV panels because any lead is sealed from air and water exposure. Individual panels damaged during the life of the solar facility are identified in days to months through either remote monitoring of system performance or from visual inspections during maintenance by onsite staff. Recently an international team of experts conducted an International Energy Agency - Photovoltaic Power Systems Programme (IEA-PVPS) study to assess if there is a public health hazard caused by lead leaching from the broken PV panels during the life of a utility-scale solar facility utilizing conservative assumptions to evaluate extreme scenarios.[14] The study examined worst-case exposure routes of soil, air, and ground water for a typical 100 MW_{AC} PV facility. For example, the worst-case residential groundwater exposure assumed that all broken panels from the entire array were within 25 feet of the groundwater well, and the chemicals released from every broken panel transported to the same groundwater well. The study found that worst-case lead exposure via air, soil, and water were each orders of magnitude less than the levels defined by the US Environmental Protection Agency (EPA) to have no adverse health effects. In the case of water, the health-screening level is the same as the maximum concentration level (MCL) set by the EPA for water quality in public water systems. This study demonstrates that there is no risk to public health from lead leached from broken PV panels.

GenX and PFAS

Following the discovery that a chemical plant near Fayetteville, NC had been dumping the unregulated chemical known as GenX into the Cape Fear river for many years, some solar opponents raised questions about the possibility of GenX or other PFAS chemicals being emitted by solar panels. PFAS chemicals are a group of chemicals informally known as “forever chemicals” due to their durability in the environment. These chemicals are found in many products, including food packaging materials, firefighting foam, and stain resistant carpet treatments. The author has not found any evidence for the existence of PFAS in PV panels, and a fact sheet from the University of Michigan entitled *Facts about solar panels: PFAS contamination* explains that PV panels do not contain PFAS and thus do not produce any PFAS contamination.[15]

PV Panel End-of-Life

PV panels last a very long time, but they do not last forever. Their output declines slightly each year, but panels rarely fail in less than 40 years. The expected economic life of utility-scale PV panels is 25-40 years, at which point they may be replaced by new panels or the entire project may be decommissioned, bringing the land back to how it was before the solar facility was installed. In both instances, the original PV panels are removed from the site. The Greensville County ordinance requires that Purdy Solar guarantee that decommissioning funds are available by depositing the needed funds in an escrow account approved by the County, so in any worst-case scenario the County will have the funds required to properly decommission the site. There are three possible fates for solar panels at the end of their economic life at a project:

- **Reuse**: Most likely when the PV panels at the Purdy Solar project are decommissioned they will still produce at least 75% of their original output and have another decade of productive life, making them most valuable to be reused as solar panels on rooftops or ground-mounted applications. Markets for used solar panels exist today and are likely to be much more mature and widely available in 30-40 years when the Purdy Solar PV panels near the end of their life.

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[14] P. Sinha, G. Heath, A. Wade, K. Komoto, 2019, Human health risk assessment methods for PV, Part 2: Breakage risks, International Energy Agency (IEA) PVPS Task 12, Report T12-15:2019. ISBN 978-3-906042-87-9, September 2019

[15] “Clean Energy in Michigan” Series, Number 12, Facts about solar panels: PFAS contamination, By Dr. Annick Anctil, http://graham.umich.edu/product/facts-about-solar-panels-pfas-contamination

- **Recycling**: Any panels that are not reused as working panels could be recycled. Currently in the US it is possible to recycle the largest constituents of PV panels using the existing glass and metal recycling infrastructure, referred to as low-value recycling. Today this recycling comes at a cost premium to disposing the panels in a landfill. However, as PV recycling technology improves and the number of panels reaching end-of-life increases dramatically, it is possible that in the future recycling PV panels will more than pay for itself. Recycling plants built specifically to recycle PV panels can recycle nearly 100% of the panel (aka high-value recycling), including the valuable silver and refined silicon they contain, and can be optimized for the task, significantly reducing the cost to recycle each panel while also significantly increasing the value of the recycled content. Until very recently only one PV-specific high-value recycling plant existed, in France, but in the coming decades it is expected that PV-specific recycling plants will become commonplace. PV recycling technology is clearly still in its infancy. However, it is expected that when the Purdy Solar PV panels reach the end of their useful life in 30+ years that the US PV recycling infrastructure will be robust, such that reuse or recycling of the PV panels will be the preferred option. It is also very possible that recycling will be required by new U.S. regulations, as it has been for years in Europe.

Figure 4. PV Panels Waiting to be Recycled (Source: LuxChemtech GmbH)

The Solar Energy Industries Association (SEIA) started the SEIA National PV Recycling Program several years ago to accelerate PV recycling in the US. Currently the program aggregates the services offered by recycling vendors and PV manufacturers, making it easier for the industry to select a cost-effective and environmentally responsible end-of-life management solution. **The program identifies Preferred Recycling Partners through an evaluation process. These partners are capable of recycling PV modules, inverters, and other related equipment today**. The current SEIA PV Recycling Partners are listed on the program's website, and full access to the program and the Preferred Recycling Partners is available to SEIA members.

- **Disposal**: If panels are not reused or recycled, federal waste management laws (Resource Recovery and Conservation Act, RCRA) require that PV panels, like any other commercial/industrial waste, be disposed of properly, which would typically be in a landfill. In order to determine the proper disposal method, RCRA requires that all commercial/industrial waste be identified as either hazardous or non-hazardous waste, which is generally determined for PV panels using the Toxic Characteristic Leaching Procedure (TCLP) test developed by the U.S. EPA. This test seeks to simulate landfill conditions and check for leaching of 8 toxic metals and 32 organic compounds. Limited data has been published about the TCLP test results of solar panels, but it is known that some older silicon panels that contain more lead than modern panels exceed the TCLP test limits for lead. Researchers at Arizona State University's Photovoltaic Reliability Laboratory have done the most robust investigation of methods for conducting accurate TCLP test on PV panels, and their latest research found that all three of the modern crystalline silicon PV panels tested passed the TCLP test, classifying them as non-hazardous waste.[16]

A worst-case scenario would be tons of PV panels being disposed of in a non-sanitary landfill, which is essentially a huge pile of garbage with little to no effort to minimize leaching from the waste. This type of landfill is illegal in many world regions, including in Virginia. A recent IEA-PVS research study on PV panels disposal risks used this worst-case situation to evaluate the potential for cancer and non-cancer hazards through comparison of predicted exposure-point concentrations in soil, air, groundwater, and surface water with risk-based screening levels created by the EPA and the World Health Organization (WHO).[17] One the report's authors, Gavin Heath with the US Department of Energy's National Renewable Energy Laboratory (NREL), summarized their findings about lead in silicon PV panels this way: "under the worst-case conditions, none of them exceeded health-screening thresholds, meaning they're not deemed to potentially

[16] Tamizhmani, G., et al. (2019). Assessing Variability in Toxicity Testing of PV Modules. In 2019 IEEE 46th Photovoltaic Specialists Conference (pp. 2475-2481). Institute of Electrical and Electronics Engineers Inc.. https://doi.org/10.1109/PVSC40753.2019.8980781
Publicly-accessible version: dev-pvreliability.ws.asu.edu/sites/default/files/93_assessing_variability_in_toxicity_testing_of_pv_modules.pdf
[17] P. Sinha, G. Heath, A. Wade, K. Komoto, Human health risk assessment methods for PV, Part 3: Module disposal risks, International Energy Agency (IEA) PVPS Task 12, Report T12-16:2020. ISBN 978-3-906042-96-1, May 2020

have significant enough risk that you'd want to do a more detailed health risk assessment."[18] The worst-case scenario defined in the research has many conservative assumptions, and thus likely overestimates the risk of disposal in a *non-sanitary* landfill. It is important to stress that Virginia only allows solid waste disposal in sanitary landfills, which are engineered facilities with plastic liners, leachate collection systems, and covers, all of which dramatically reduce the potential for human exposure compared to the non-sanitary landfill assumed in the study. This and other research show that if the Purdy Solar PV panels are disposed of in a landfill they will not create any negative public health impact.

In 2019 the North Carolina legislature passed HB 329 (S.L. 2019-132), requiring the NC Department of Environmental Quality (DEQ) to prepare a report to guide rulemaking regarding decommission of solar PV and other renewable energy facilities and proper disposal of their equipment. While the policy recommendations in the report do not apply to Virginia, the report, issued January 1, 2021 and titled *Final Report on the Activities Conducted to Establish a Regulatory Program for the Management and Decommissioning of Renewable Energy Equipment*, provides a thorough discussion addressing many questions landowners and communities may have about solar decommissioning that are applicable in Virginia. NC DEQ compiled the input and commentary of numerous stakeholders, including the renewable energy industry, environmental organizations, and academia, including the author and NC State University's Clean Energy Technology Center. The report is well researched and very informative. NC DEQ provides several key findings and recommendations, but no recommendations for changes in NC regulations of solar facilities. One of the report's key findings is that "According to Division of Waste Management experts, if every end-of-life PV module is disposed of in landfills, landfill capacities will not be negatively impacted."

Contents of Batteries

The components of lithium-ion batteries vary because there are many different battery chemistries in use and several different cell construction types. And while lithium itself is non-toxic, some lithium-ion batteries do include some toxic heavy metals such as cobalt, nickel, or manganese; although the lithium iron phosphate (LFP) battery chemistry that will be used at Purdy Solar does not contain any of these heavy metals. During the operational life of the batteries any metals in the cells are sealed inside of the batteries and thus have no impact on human health. The solvent-based liquid electrolyte in each cell is very difficult to get to leak out of a cell and will quickly evaporate if it does. In addition to the battery cells, the battery system also includes a battery management system that consists of sensors, switches, and similar controls equipment. The battery enclosure is typically an outdoor-rated steel enclosure.

Batteries End-of-Life

The performance of stationary batteries slowly degrades, eventually resulting in enough reduction of energy capacity that the battery is considered to have reached the end of its life. The expected lifespan of lithium-ion batteries is on the order of 10 to 20 years, with LFP batteries general having longer lives than most other chemistries.

At the end of its life the batteries will be safely decommissioned, which will involve de-energizing the batteries to a low voltage, disconnecting each battery module from the system, removing battery modules and associated components, preparing the list of materials and components for removal, disposal, or recycling, and then shipping them to their next location. Transport of some battery components, including shipping via a shipping provider, is regulated by the United States Department of Transportation (U.S DOT).

Most of the non-battery components of the system have readily available scrap markets, such as steel, aluminum, and copper. Much like end-of-life PV modules, end-of-life batteries can be repurposed for second life applications, recycled, or landfilled.

- **Recycling** – Lithium-ion batteries are recyclable. Currently only a small percentage of lithium-ion batteries are recycled, and no facility in the US can fully recycle lithium-ion batteries into battery constituents ready to build new lithium-ion batteries. While there are many challenges to creating a robust, cost-effective collection and recycling industry for lithium-ion batteries, it does appear to be technically possible. The US Department of Energy as well as several industry

[18] Green Tech Media, Landfilling Old Solar Panels Likely Safe for Humans, IEA Research Suggests, April 2020, www.greentechmedia.com/articles/read/solar-panel-landfill-deemed-safe-as-recycling-options-grow

groups and private companies are investing in research and development that they hope will lead to widespread recycling of lithium-ion batteries in the US.

- **Disposal –** When batteries are not repurposed or recycled, batteries are disposed as waste. Battery disposal is governed by EPA Universal Waste rules, which require waste handlers to separate hazardous materials for disposal under federal laws but allow the disposal of the remaining non-hazardous waste per state and local requirements. Once the fire risk is removed from the batteries (either by mechanical or chemical means), non-hazardous materials not recovered for reuse or recycling can be disposed of through municipal waste streams. While some lithium chemistries are considered non-hazardous, many batteries have toxic constituents that require treatment as hazardous materials. The potential toxicity of Li-ion battery materials varies widely by chemistry; for example, where nickel, cobalt, or lead are present in battery chemistries in significant quantities, precautions must be taken at disposal or incineration sites in line with the hazards of those individual materials.[19]

Toxicity: Operations & Maintenance

The operations and maintenance (O&M) activities for a solar and battery energy storage site are rather limited. Often the most significant effort is maintenance of the vegetation on the site. The PV equipment and the battery equipment require some, but limited, scheduled and unscheduled maintenance.

Site and Solar Operations & Maintenance

The only two aspects of operations and maintenance (O&M) of solar system that have raised concerns about toxicity are the fluids used to wash PV panels and herbicides used to maintain vegetation.

- **Panel Washing** – Across VA there is ample rain to keep the panels clean. If the panels need to be washed, it would occur infrequently and typically with use of only deionized water and cleaning brushes.

- **Herbicides** – The industry standard practice for maintaining the vegetation at solar facilities is similar to how most cities maintain their parks, which is they primarily rely on mowing and string trimmers for vegetation management, and use herbicides along fences, in roads, and around some equipment. Parks and solar facilities also use herbicides to strategically remove problem weeds, especially woody weeds, to maintain a healthy cover of the desired species of grasses and other low-growing vegetation. This mode of herbicide use applies significantly less than the herbicide volume commonly applied in VA agriculture. For example, Round-Up-Ready crops are common row crops that have been engineered for the entire field, including the crops, to be sprayed with Round-Up (glyphosate) several times each season. Additionally, farmers applying most types of herbicides to their fields are not required to be certified or licensed, but a VA commercial pesticide applicators license is required to apply any herbicide to a solar facility. At Purdy Solar, the Greensville County solar ordinance requires that the site notify the County prior to application of pesticides and fertilizers.

Batteries Operation and Maintenance

Battery operation does not produce any emissions, and they require very little maintenance during their operating lifetime. The battery systems require some scheduled maintenance for things like cleaning HVAC air filters and annual or semi-annual visual checks of electrical connections. Some systems use an anti-freeze liquid coolant that might require replacement during the life of the system, but this does not pose any health or safety hazard.

Sources for Further Reading on Toxicity/End-of-Life:

- International Renewable Energy Agency (IRENA): End-of-Life management: Solar Photovoltaic Panels, June 2016
- Electric Power Research Institute (EPRI): Environmental and Economic Considerations for PV Module End-of-Life Management, December 2018
- EPRI: Feasibility Study on Photovoltaic Module Recycling in the United States, April 2018
- EPRI: Solar Photovoltaics End of Life Management Infographic, March 2021
- National Renewable Energy Laboratory (NREL): A Circular economy for PV system materials, April 2021

[19] Energy Storage Association (ESA), End-of-Life Management of Lithium-ion Energy Storage Systems, April 2020, https://energystorage.org/wp/wp-content/uploads/2020/04/ESA-End-of-Life-White-Paper-CRI.pdf

- North Carolina Department of Environmental Quality: Final Report on the Activities Conducted to Establish a Regulatory Program for the Management and Decommissioning of Renewable Energy Equipment, January 2021
- Energy Storage Association (ESA): End-of-Life Management of Lithium-ion Energy Storage Systems, April 2020
- EPRI: Lithium Ion Battery Energy Storage End of Life Management Infographic, April 2021
- ReCell Center: A national collaboration of industry, academia and national laboratories working together to advance recycling technologies along the entire battery life-cycle for current and future battery chemistries (website)
- NAATBatt: Laws, Regulations and Best Practices for Lithium Battery Packaging, Transport and Recycling in the United States and Canada (webpage)

Electromagnetic Fields (EMF)

Exposure to EMF, or electric and magnetic fields, is a fact of everyday modern life. Electromagnetic fields come in many different frequencies, ranging from grid electricity with a frequency of 60 hertz to x-rays and gamma rays that are billions of billions of times faster. The faster the frequency the stronger the EMF. The EMF coming from grid electricity, including from the inverters, transformers, and AC wires to be used at the Purdy Solar facility, has much lower frequency and therefore much lower energy than the EMF from cell phones, wireless internet, and even radio and TV towers. The solar panels, the batteries, and the wires connecting both of them to the inverters carry direct current (DC) electricity, which has a frequency of zero hertz, and thus produces static electric and magnetic fields. The voltage and current of these circuits are both relatively low, so the electric and magnetic fields they produce are both rather weak. The static magnetic fields the PV panels generate are much weaker than the Earth's natural static magnetic field, which can be demonstrated by a compass still pointing north when placed near the panels.

Electric fields are created around wires and equipment wherever a voltage exists, however it is easily blocked with common materials such as metal, wood, and soil. 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.[20] The proposed solar project does not produce any voltages higher than the existing power lines, and therefore does not produce any electric fields not generally encountered by members of the public.

Magnetic fields are the other aspect of EMF, and they are created by electric current. Typical Americans are exposed to about 1 milligauss of magnetic field from grid electricity on average during their day, primarily from sources at homes and work[21]. The primary source of magnetic fields in a solar facility are the inverters and the short section of wires between each central inverter and its step-up transformer. To convert direct current to alternating current inverters use a series of switches that turn off and on several thousand times a second, creating EMF in the range of 5 kHz to 100 kHz, which is much faster than the 60 Hz of grid electricity but still much slower than even the lowest frequency radio signals. Also, the energy output of inverters has the highest electrical current of any portion of the solar facility, making the few feet of wire between the inverter and the transformer the source for the strongest magnetic fields in the facility, yet because the strength of a magnetic field decreases dramatically with increasing distance from the source these magnetic fields only extend about 150 feet from the inverter, which is less than the distance from each inverter to the perimeter of the Purdy Solar project, at which point they measure less than 0.5 milligauss.[22] Similarly, the magnetic fields from substations generally do not extend far enough to leave the fence around the substation, so the same can be expected for the Project's substation.[23]

The bottom line is that the EMF from the Purdy Solar PV system will not leave the solar site boundary, and thus will not increase the EMF exposure of any neighbors. Even if some EMF from the PV facility were to extend beyond the fenced perimeter of the site, there would still be no public health impact because low levels of extremely low frequency (ELF) EMF

[20] WHO factsheet: Electromagnetic fields and public health, Exposure to extremely low frequency fields, June 2007, www.who.int/peh-emf/publications/facts/fs322/en/

[21] World Health Organization (WHO), webpage: Electromagnetic Fields – Typical exposure levels at home and in the environment, www.who.int/peh-emf/about/WhatisEMF/en/index3.html

[22] Study of Acoustic and EMF Levels from Solar Photovoltaic Projects. Tech Environmental, Inc., December 2012, www.masscec.com/study-acoustic-and-emf-levels-solar-photovoltaic-projects

[23] www.niehs.nih.gov/health/materials/electric_and_magnetic_fields_associated_with_the_use_of_electric_power_questions_and_answers_english_508.pdf

exposure are not harmful to humans. After extensive study of the potential health impacts of EMF from grid electricity the World Health Organization (WHO) concludes:

> *"Despite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health."*[24]

Sources for Further Reading on EMF:

- Electric Power Research Institute (EPRI): EMF and Your Health: 2019 Update and emf.epri.com
- World Health Organization (WHO): www.who.int/peh-emf/about/WhatisEMF

Heat Island Effect

The localized effects of large-scale PV facilities on temperature and moisture are not yet well understood. However, the localized micro-climate effects of large-scale PV facilities are understood well enough to determine that they do not create a heat island effect similar to the well-documented urban heat island effect from dark, massive, surfaces in urban environments, such as asphalt paved streets and parking lots, that cause urban areas to be significantly warmer than the surrounding rural area during the day and night. The changes that solar panels may make to the way land absorbs, reflects, and emits the energy from sunlight are minimal compared to the changes created by buildings, vehicles, and many miles of concrete and asphalt. By comparison, solar panels absorb and reflect a similar amount of solar energy as vegetation and soil. Solar panels are lightweight and cannot store large amounts of thermal energy, and the ground remains covered in vegetation with its natural exposure to air and water.

Initial research into the potential for PV systems to cause a heat island effect have used a variety of techniques, including conceptual energy flow calculations, advanced fluid dynamic computer simulations, and field measurements of temperature.[25, 26, 27] This research found a range of different effects on temperature, but none indicate that a large PV system could affect the temperature of the surrounding community. Most found that compared to similar undeveloped land the air temperature in a solar facility increases during the day, but the nighttime results were mixed. Some studies found PV sites to be cooler than non-PV sites at night, but others found them to be warmer. Much of this variation is likely explained by the different climates studied but may also be due to the different methods of the studies. Much of the research on solar heat island effect occurred in arid regions of the U.S. southwest where the results are unlikely to translate perfectly to wetter climates in the southeast. In a written statement of evidence Greg Barron-Gafford, leading solar heat island effect researcher, says that he expects that when the area under the PV array is vegetated with grass that the localized heat island effect his research found in dry climates will be greatly reduced.[28]

The available studies agree that the slight increase of air temperature in the PV site dissipates quickly with height and distance from the panels as natural processes remove and spread the heat. As a result, any temperature increase that may occur at the Purdy Solar project during the day will be limited to the site and will not increase the temperature of any of the surrounding community.

Sources for Further Reading on Heat Island Effect:

- EPA: Learn about heat islands: www.epa.gov/heatislands/learn-about-heat-islands

[24] World Health Organization (WHO), webpage: Electromagnetic Fields – Summary of health effects, www.who.int/peh-emf/about/WhatisEMF/en/index1.html
[25] Broadbent, Ashley & Krayenhoff, Eric & Georgescu, Matei & Sailor, David. (2019). The Observed Effects of Utility-Scale Photovoltaics on Near-Surface Air Temperature and Energy Balance. Journal of Applied Meteorology and Climatology. 58. 10.1175/JAMC-D-18-0271.1.
[26] Barron-Gafford, G. A. et al. The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. Sci. Rep. 6, 35070; doi: 10.1038/srep35070 (2016).
[27] V. Fthenakis and Y. Yu, "Analysis of the potential for a heat island effect in large solar farms," 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC), Tampa, FL, 2013, pp. 3362-3366, doi: 10.1109/PVSC.2013.6745171.
[28] G. Barron-Gafford, Statement of Evidence by Greg Barron-Gafford on Solar Heat Islanding Issues, May 2018, www.planning.vic.gov.au/__data/assets/pdf_file/0024/126555/301-Expert-Witness-Statement-of-G-Barron-Gafford-PVHI-May-2018-Lemnos.pdf

Glare

Photovoltaic panels are designed to absorb, and thus not reflect, the solar energy that they receive. However, when sunlight strikes the glass front of a solar panel at a glancing angle a significant portion of the solar radiation is reflected, which can potentially lead to solar glint (a brief flash) or glare. Glint or glare can temporarily impact a person's vision, including pilots landing aircraft, or motorists driving vehicles. However, the conditions required for a PV project to create glare rarely occur. PV facilities, such as Purdy Solar, that utilize single axis trackers to slowly rotate the solar panels to follow the sun have even less potential to create glare because the trackers help avoid a situation where sunlight hits the panels at a glancing angle. Most modern trackers implement an advanced control strategy known as "backtracking" that increases the electricity production of the site by flattening the tilt of the panels early and late in the day to keep the rows of solar panels from shading one another. Backtracking can result in brief periods near sunrise and sunset where the sun strikes the panels at a glancing angle, creating a situation that could result in a few minutes of visible glare at sunrise and sunset. For anyone to see this glare they must be looking across the solar panels in the direction of the rising or setting sun, which is a situation where the sun obviously will create significant glare for the viewer with or without the solar project.

Figure 5. 20 MW PV System at Indianapolis International Airport (Photo source: inhabitat.com)

A clear indication of the lack of glare problems from large ground-mounted PV systems are the PV systems installed on airports across the U.S., including Denver International and Indianapolis International. While there is the potential for a PV system to create glare there is also the ability to predict when and where a system may create glare and incorporate any needed mitigation before construction. The Federal Aviation Administration (FAA) and the U.S. Department of Energy developed specialized solar glare analysis software to predict when and where a PV project may produce glint or glare for sensitive receptors nearby. The closest airport to the Purdy Solar project is the Emporia Greensville Regional Airport (EMV) located roughly 7 miles southeast of the site. Based on my understanding of solar glare and my experience conducting numerous glint and glare studies using the Forge Solar software, I would not expect Purdy Solar to produce any glare hazards.

Sources for Further Reading on Solar Glare:

- National Renewable Energy Laboratory (NREL): Webpage on glare impacts from PV www.nrel.gov/state-local-tribal/blog/posts/research-and-analysis-demonstrate-the-lack-of-impacts-of-glare-from-photovoltaic-modules.html
- ForgeSolar: Solar glare analysis software documentation covering solar glare fundamentals www.forgesolar.com/help/

Conclusions

Based on my knowledge of engineering and science, personal experience with PV and battery technology, review of academic research, and review of materials provided by Renewable Energy Services and Palladium Energy about the proposed Purdy Solar PV and battery energy storage facility in Greensville County, Virginia, my findings and opinions are summarized as follows:

- The development and operation of the Purdy Solar PV and battery facility will not result in any environmental contamination or negative impacts to public health or safety.
- The Purdy Solar facility will not increase the temperature of the area surrounding the site.
- The Purdy Solar facility is not expected to create any glare hazards or other negative glare impacts.