Design of a Home Solar System

Evie Cooper

As the prices of energy continue to increase, more and more homeowners are looking at the possibility of installing home solar systems; I certainly am myself. As photovoltaic technology continues to improve, now is a great time to build a home solar system. Of course, not all solar systems are photovoltaic in nature: this presentation will discuss the design of, pitfalls of, and installation of thermal solar systems as well. Since safety is of a great concern handling electricity and potentially hot fluids, a discussion of that will be provided -- all presentation elements will be supplemented by graphics.

Hybrid Energy System

Muntasir Elhaj

Hybrid energy systems have emerged as a promising solution to address the growing demand for reliable, cost-effective, and environmentally sustainable electricity, particularly in regions with limited grid access. Sudan's energy sector remains heavily dependent on fossil fuels, which account for approximately 52% of primary energy consumption, while hydropower contributes around 42%, highlighting the need for diversification toward cleaner energy sources. In line with national energy strategies aiming to increase renewable energy penetration, this study investigates the design and optimization of a stand-alone hybrid energy system for domestic applications in southern Sudan. The proposed system integrates photovoltaic (PV) panels, wind turbines, diesel generators, and battery storage to enhance reliability while minimizing operational costs and environmental impact. The selected study area is characterized by high solar irradiance and moderate wind potential, making it suitable for hybrid renewable energy deployment. Real-world meteorological data, including solar radiation, temperature, and wind speed, were utilized alongside load profile analysis to develop an optimized system model. The system design, simulation, and techno-economic optimization were carried out using Hybrid Optimization of Multiple Energy Resources (HOMER) and MATLAB tools, considering a project lifetime of 24 years. The optimization process focuses on minimizing the levelized cost of energy (LCOE), reducing fuel consumption, and lowering greenhouse gas emissions while ensuring a reliable and continuous power supply. According to the economic analysis results presented in the study, the hybrid system significantly reduces operational costs and total net present cost compared to a diesel-only system. Furthermore, emission analysis demonstrates substantial reductions across all major pollutants, with carbon dioxide emissions decreasing from over 6 million kg/year in the base system to approximately 2.9 million kg/year in the hybrid configuration.

Photovoltaic Application: Residential Rooftop and Solar Garden

Jinrui Lan

As distributed PV continues to expand, two models have merged as dominant deployment strategies: individual owned residential rooftop systems and community solar gardens. While both contribute to renewable energy targets and carbon reduction. This prestation will examine the technical, economic, and social dimensions of these two PV applications. The objective is to do analysis of how each model contributes to sustainable energy adoption with the consideration of costs and user accessibility.

Residential rooftop PV systems convert sunlight directly into electricity using the photovoltaic effect, where semiconductor materials generate electric current when exposed to light. As sunlight hits the solar panels, the electricity (DC) is generated. Then, using the inverter converts DC to AC power. The key advantage of rooftop PV systems is reducing electricity costs. Then, solar gardens are built in suitable location where electricity generated is fed into the local power grid, which is not needed for on-site installation.

Residential rooftop PV systems have an ability to generate electricity directly at the point of use, which can reduce transmission losses and enable independence. However, these systems often require significant investment and suitable roof conditions. In contrast, solar gardens provide shared access to solar energy for multiple participants including renters or individuals without viable rooftop space. The presentation will compare these two models based on installation, maintenance costs, energy efficiency, and accessibility.

Designing A Home-Based Photovoltaic System

Breanna Laski

Residential photovoltaic (PV) systems provide an effective means of reducing reliance on grid-supplied power. This project examines the design and feasibility of a home-based PV installation for a residential property in LaGrange. The region receives an average daily solar irradiance of approximately 5.7 kWh/m^2/day, placing it within a high-yield solar zone and indicating strong potential for solar energy generation, as reported by SolarRadiance.energy. The presence of several nearby solar farms further supports the suitability of the area for PV deployment and demonstrates the viability of large-scale solar integration within the local grid infrastructure. Despite favorable solar conditions, economic factors present notable challenges. The local utility provider, Diverse Power, does not offer net metering or buyback programs for excess residential solar production. This limitation significantly affects system economics by extending the payback period and eliminating potential revenue from surplus power generation. As a result, system design must prioritize self-consumption of generated energy rather than reliance on exporting excess power to the grid. Additional considerations such as installation costs, system efficiency, and long-term maintenance further influence overall feasibility. The practical motivation for this project is the evaluation of installing a PV array on a nearby pole-barn structure with a roof of approximately 20 ft by 80 ft. This larger surface area allows for a greater number of PV modules compared to the house roof, enabling higher generation capacity but also increasing upfront installation costs. Furthermore, the structural orientation and tilt of the barn roof introduce additional design considerations that may impact overall system performance and energy yield. The primary objective of this project is to assess the technical and economic feasibility of the proposed system. This includes determining the required system size, estimating expected energy output, and evaluating the system's ability to reduce dependence on the grid. The analysis also aims to provide insight into whether such a system can achieve a practical balance between cost, performance, and long-term energy savings for residential applications in similar regions

Graphene/Silicon Heterojunction Solar Cells: Resolving the Trade-off Between Optical Light-Trapping and Interfacial Passivation

Wen-Chieh Lee

Graphene/Silicon (Gr/Si) heterojunction solar cells have emerged as a promising, cost-effective alternative to traditional diffused-junction silicon photovoltaics due to graphene's exceptional transparency, high carrier mobility, and tunable work function. However, realizing the theoretical maximum efficiency of Gr/Si devices is fundamentally hindered by a critical engineering trade-off: optimizing the silicon surface for maximum optical absorption (light-trapping) often severely degrades the continuous electrical contact of the overlaid graphene sheet. This presentation provides a comprehensive analysis of this fabrication dilemma, integrating primary experimental data on Gr/Si Schottky junctions with a systematic review of contemporary 2025 literature. Initial sections will evaluate the morphological and electrical impacts of pyramidal texturing on silicon substrates, utilizing Scanning Electron Microscope (SEM) imagery and Raman spectroscopy to demonstrate how surface roughness increases sheet resistance while UV-Vis reflectance spectra confirm superior light-trapping capabilities. To overcome these inherent limitations, the presentation will analyze recent state-of-the-art advancements in both optical and electrical engineering. Optically, the integration of a one-step transferred poly(methyl methacrylate) (PMMA) anti-reflection coating (ARC) is examined for its dual role in mitigating air/Si interfacial reflection losses and protecting the graphene from environmental degradation. Electrically, the introduction of ultra-thin interfacial passivation layers, specifically ALD-grown Al_2O_3 in metal-insulator-semiconductor (MIS) architectures, is evaluated. By comparing synthesized I-V characteristic data and RSoft optical simulations, this presentation demonstrates how the synergistic application of advanced anti-reflection coatings and passivating interlayers effectively suppresses carrier recombination, enhances the open-circuit voltage (V_{oc}), and provides a viable pathway toward highly efficient and stable Gr/Si photovoltaics.

Solar Photovoltaics in Costa Rica

John Li

While Costa Rica is being known for its exotic biodiversity and its practice of using renewable energy for electricity, less than one percent of its energy are from solar photovoltaics, majorily being from hydroelectric dams (La Fortuna & Orotina). Even though the country has an average irradiance of 4.5–5.5 KiloWatts per day meters squared, the Instituto Costarricense de Electricidad (ICE) and Compañía Nacional de Fuerza y Luz (CNFL) have little to no competition, presenting a near monopoly like companies who control generation, transmission and distribution of electricity. However, with growing recent weather issues such as El Nino during 2023-204 which caused majority period of droughts, forcing the country to generate 4.5% of energy using oil reserve tanks. As a result of these uncertanties, using solar PVs gave a different perspective on production of electricity.

Recent reforms such as Ley 22,009 permit distribution of electricity and energy, so individual customers and hoseholds do not have to entirely focus on ICE/CNFL. CNFL & ICE are also planning to expand its production using Solar PV, who are already producing over 123 Gigawatts per hour. Other small-scale presences of solar PVs are starting to appear as well in the country. With global PV and battery costs decreasing each year, photovoltaics will certainly contribute more to Costa Rica’s energy manufacturing.

Power Grid Integration Analysis of Large- and Small-Scale PV Systems: Technology, Stability, and Economics

Shreyasee Mandal

The rapid growth of photovoltaic (PV) systems has introduced significant technical, operational, and economic challenges for modern AC power grids. This study examines the integration of both large-scale utility PV plants and small-scale distributed PV systems, focusing on their distinct impacts on grid stability, power quality, and system operation. Large-scale PV systems primarily influence bulk power flow, voltage regulation, and frequency stability due to their inverter-based nature and lack of inherent inertia, requiring advanced control strategies, dynamic reactive power support, and fast-ramping backup resources. In contrast, small-scale PV systems at the distribution level introduce challenges such as reverse power flow, feeder overvoltage, harmonic distortion, and protection coordination issues, especially under high rooftop penetration.

The analysis incorporates the concept of the duck curve to illustrate how high levels of distributed PV generation lead to midday net-load reductions and steep evening ramping requirements, increasing system stress and flexibility demands. Economic considerations, including cost reduction benefits and infrastructure upgrade requirements, are also evaluated. To support this analysis, the study integrates theoretical foundations from PV system modelling, inverter control, and grid stability, along with real-world data.

Case studies of China, California, South Australia, and India are used to compare different stages of PV integration. These highlight challenges such as curtailment in large-scale systems, inverter-dominant grid behaviour, and emerging-grid constraints, including India's role in the International Solar Alliance. The study provides a comprehensive understanding of multi-scale PV integration and its implications for future grid modernization.

Photovoltaics in Austria and Germany

Adam K. Paugh

Austria is committed to achieving a carbon-neutral electricity sector by 2030, causing rapid expansion of PV in conjunction with existing hydroelectric resources. Germany, through its Energiewende (Energy Transition) initiative, is pursuing deep reductions in greenhouse gas emissions, targeting climate neutrality by 2045. These policy goals directly influence system design requirements, particularly in addressing seasonal generation mismatches and ensuring long-term grid stability. This research investigates the scientific and engineering principles underlying photovoltaic (PV) deployment in Germany and Austria with emphasis on power system behavior, device performance, and grid integration.

Even with moderate solar irradiance conditions, both countries have achieved high PV market penetration, providing a unique platform to study the interaction between PV and traditional power systems. The analysis begins with an evaluation of regional solar resource characteristics, including the effects of diffuse irradiance, seasonal variability, and temperature-dependent efficiency on PV performance. An additional focus of this work is the role of power electronics in enabling reliable PV integration. As inverter-based resources displace synchronous generation, both Germany and Austria face reduced system inertia, altered fault current characteristics, and increased sensitivity to voltage and frequency disturbances. The research examines inverter control strategies, including grid-following and grid-forming approaches, as well as reactive power support and voltage regulation schemes defined by modern grid codes. Additionally, the coupling of PV with energy storage systems, such as distributed lithium-ion batteries in Germany and pumped hydro storage in Austria, is considered to assess their impact on mitigating intermittency and stabilizing system operation.

Overall, Germany and Austria are vital case studies for the scientific challenges associated with high PV penetration, offering insight into the evolving architecture of modern electrical power systems under aggressive decarbonization mandates. Each country provides valuable lessons for renewable power grid integration as we progress into cleaner methods of power.

Perovskite-on-Silicon Tandem Solar Cells

Sam Pratt

Perovskite-on-silicon tandem solar cells are one of the most exciting new directions in photovoltaics because they stack two different solar materials together to use sunlight more efficiently than standard silicon alone. The perovskite top cell captures one part of the solar spectrum while the silicon bottom cell captures the rest, which allows the device to reach much higher efficiency. This topic is especially important today because the field is no longer focused only on tiny lab devices. Researchers are now showing that these tandems can work on real industrial textured silicon surfaces and at much larger sizes, which makes the technology feel much closer to real products.

This presentation will explain the basic idea behind tandem solar cells, why perovskites are attractive, and why silicon by itself is starting to reach its practical limits. It will then focus on the biggest recent advances, including strong certified results on industrial textured silicon, larger-area tandem devices, and early module-scale progress. Just as important, it will also explain what still stands in the way of widespread commercial use. Even though the efficiencies are now very impressive, the main challenge is proving that these devices can be made reliably at large scale and can survive long-term use in real outdoor conditions. The main message of the talk is that 2025 appears to be a turning point: perovskite-on-silicon tandems are moving from record lab cells toward realistic commercial technology, but reliability, manufacturing yield, and bankability are now the issues that matter most.

AI-Powered Solar Power Forecasting: From Raw Data to Reliable Predictions

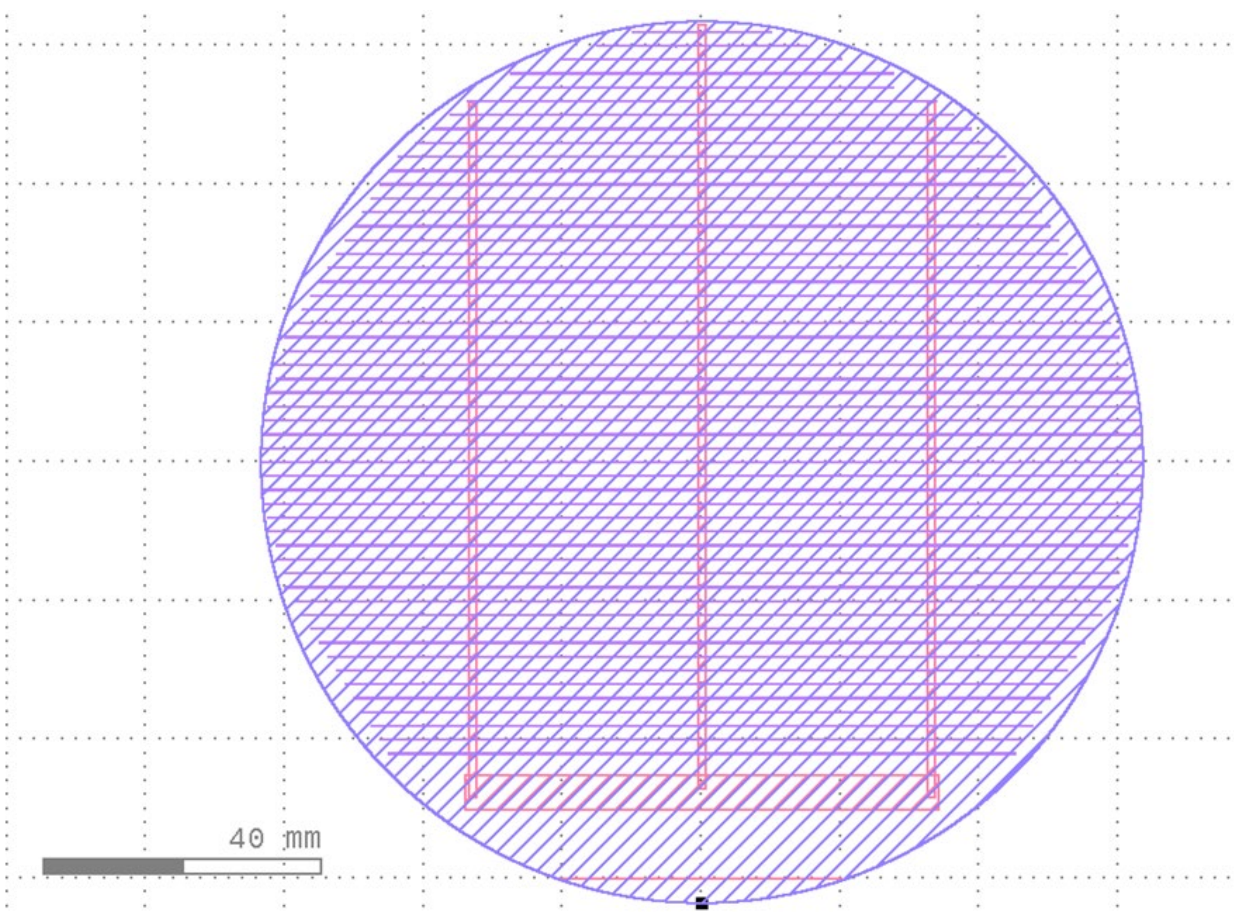
Md Mizanur Rahman

This study presents a comprehensive evaluation of Machine Learning (ML) and Artificial Intelligence (AI) models for short-term solar power forecasting, addressing the critical need for reliable predictions in modern renewable-rich power systems. Accurate forecasting of solar power (SP) is essential for optimal grid operation, especially given the inherently uncertain and highly volatile nature of photovoltaic (PV) generation. Using one year of high-granularity (15-minute) PV generation and weather data from the Unisolar open dataset—specifically from a site at La Trobe University, Victoria, Australia—the analysis incorporates key meteorological variables including apparent temperature, air temperature, dew point temperature, relative humidity, wind speed, and wind direction. Robust preprocessing steps were applied, including missing-value handling and feature engineering. Time-series analysis techniques such as the Augmented Dickey–Fuller (ADF) test, Autocorrelation Function (ACF), Partial Autocorrelation Function (PACF), and seasonal decomposition revealed a strong 24-hour periodicity, motivating the use of a 96-step look-back window for model training. To establish a performance baseline, several classical ML models (Linear Regression, Random Forest, XGBoost, ARIMA) were first evaluated. These baseline results provided essential insight into the limitations of traditional approaches when modeling nonlinear and highly variable solar generation. Building on this foundation, advanced deep learning architectures—including Feedforward Neural Networks (FFNN), Long Short-Term Memory (LSTM), Gated Recurrent Units (GRU), Convolutional Neural Networks (CNN), and a Hybrid FFNN-XGBoost model—were subsequently explored. Among all models, the CNN-LSTM architecture consistently achieved the best performance, with a minimum RMSE of 5.836, MAE of 2.848, and an R-squared value of 0.955, establishing it as the most effective model for this forecasting task. Horizon-based evaluation demonstrated that forecasting accuracy decreases as the prediction horizon increases. As expected, the 30-minute horizon produced the lowest error across all models due to minimal propagation of uncertainty. However, the 6-hour horizon exhibited error metrics remarkably close to the 30-minute results for the CNN-LSTM model (RMSE 0.049 vs. 0.076), indicating strong temporal generalization and making the 6-hour forecast a practical and feasible choice for real-world grid operations, where medium-range forecasts are essential for scheduling, reserve allocation, and energy market participation. The strong performance of these AI-powered techniques—grounded in rigorous time-series analysis and leveraging a comprehensive open dataset—highlights their potential to significantly enhance solar generation predictability and support more efficient, stable, and intelligent power system management. Future work will focus on advanced hyperparameter optimization and more sophisticated feature engineering to further improve forecasting accuracy and model robustness.

Fabrication of Single Crystalline Silicon PV Cell

Peter J. Ray

Single crystalline silicon remains the industry-standard photovoltaic (PV) technology due to its high efficiency, manufacturing scalability, and non-toxic material profile. This project details the fabrication of a single crystalline cell within the Auburn Microelectronic Fabrication Lab, utilizing a 4-inch diameter, heavily p-doped silicon substrate. This PV cell will include an SiN_x anti-reflective coating (ARC) to optimize light-trapping, titanium-copper traces and back contact, and use of spin-on dopant. The following presentation outlines the design, fabrication, and characterization phases while evaluating critical performance tradeoffs.



PV Projects and Development in Africa

Kyle R. VanKirk

Despite being positioned with nearly 60% of the world's most productive solar resources, only about 3% of Africa's electricity generation was met with photovoltaics (PV) in 2023. Instead, coal and natural gas constituted most of electricity generation in the region. Africa also faces unique challenges, as over 600 million people across the continent lack access to electricity. Given these conditions, PV technologies are uniquely suited for rapid deployment across the region. Emerging solar applications and developments are positioned to address energy poverty, promote economic growth, and reduce environmental impacts across the continent. This project provides an overview of PV development in Africa, examining both large scale utility solar farms and decentralized solutions like solar mini grids which serve rural regions. In addition, the study considers how regional differences in solar irradiance, energy demand, and government policy might affect PV deployment in different areas. The study integrates multiple sources of information to assess the technical feasibility, economic viability, and social impacts of PV in different parts of Africa. Results suggest that solar PV has great potential to improve quality of life in rural areas, provide new jobs, and reduce greenhouse emissions in the region. Despite these benefits, many challenges remain. In many African countries, capital costs for installing PV projects can be between three to seven times higher than in other developed countries. Additionally, regulatory and policy inconsistencies, limited infrastructure, and financing constraints are primary obstacles that have slowed PV adoption in certain regions of the continent. Nonetheless, solar energy remains a reliable and sustainable energy option, provided that government support, investment incentives, and public-private partnerships are established. Overall, this report highlights both the opportunities and constraints that PV is facing in Africa to give a picture of possible future energy infrastructure and development in the region.

ROSA: Roll Out Solar Arrays

Ryan Buss

The roll-out solar array (ROSA) was developed by Redwire and features a flexible solar array designed to provide more power at a lower mass and volume. The development of this array began by being deployed as a technology demonstration on the robotic arm of the International Space Station (ISS). After successful demonstration of the technology the ISS received more six larger ROSAs, which have already been deployed, providing an additional 160 kW of power to the station. The Double Asteroid Redirection Test (DART) mission, also featured the two 28-foot long ROSAs, providing 6.5 kW of power to the spacecraft. This mission also included a new type of solar module within the ROSA called the Flexible Array Concentrator Technology (FACT). By incorporating the FACT into the array, half of the cells are removed and replaced by small mirror elements that focus solar radiation onto the cells themselves. By incorporating the FACT configuration the ROSA can produce more power for less size and at a lower cost. The final ROSA project discussed in this presentation is used as the power source for the Lunar Gateway Program. For the Gateway program Redwire is providing two ROSAs each about 60 feet long and providing 60 kW of power to the station. Because Gateway is a human rated vehicle – unlike DART – and its mission takes it to environments that the ISS doesn't experience in Low Earth Orbit, some additional tests have been performed to show that the ROSA system will be able to carry out its functions. For instance a 'combined environment' test campaign was done by the Space Environmental Effects (SEE) team at Marshall Space Flight Center. These tests included exposing the solar cells and small arrays to ultraviolet radiation, electron/proton radiation, xenon ion plumes, thermal-vacuum cycles, and electrostatic discharges. Since the design life of Gateway is 15 years, ensuring that the ROSA systems will provide power to the vehicle throughout the lifecycle is very important.

Photovoltaic Technologies with an Emphasis on Silicon Solar Cells

Kody Pham

This presentation examines photovoltaic (PV) technologies with a primary focus on silicon-based solar cells, which currently dominate the global solar energy market due to their favorable balance of efficiency, cost, and long-term reliability. The discussion begins with an overview of the fundamental operating principles of photovoltaic devices, including the behavior of the p–n junction under illumination, the generation of electron–hole pairs, and the role of the built-in electric field in separating charge carriers to produce electrical current. Key electrical characteristics such as the current–voltage (I–V) relationship, short-circuit current, open-circuit voltage, fill factor, and overall conversion efficiency are introduced to provide a foundation for evaluating device performance. In addition, major loss mechanisms—including carrier recombination, resistive losses, and optical reflection—are discussed to highlight the limitations that impact efficiency.

The presentation further explores different types of silicon solar cells, including monocrystalline and polycrystalline technologies, with an emphasis on their structural differences and performance trade-offs. Modern high-efficiency silicon cell architectures are also examined, including Passivated Emitter and Rear Cell (PERC), Tunnel Oxide Passivated Contact (TOPCon), and heterojunction (HJT) designs, which have significantly improved efficiency through advanced surface passivation and reduced recombination. A high-level overview of the silicon solar cell manufacturing process is provided, including silicon purification, wafer fabrication, doping, and metallization, along with recent industry trends such as decreasing cost per watt and increasing large-scale deployment.

Finally, the presentation discusses future directions in photovoltaic technology, including tandem solar cells that combine silicon with emerging materials to surpass traditional efficiency limits. Overall, this work highlights the critical role of silicon photovoltaic technology in advancing sustainable energy systems and its continued importance in meeting global energy demands.

Home PV System: Auburn, AL vs. Selb, BY

Hayden Williams

Photovoltaic systems have become popular options for homes to generate their own energy in both the United States and Germany. However, these two countries differ in their regulations, commercial options, and environments. Policy in Germany is more favorable to homeowners implementing their own systems when compared specifically to Auburn, Alabama, where the climate is more optimal for solar irradiance.

Jan Golgrebe, a Selb resident, implemented his own PV system to resist increasing energy prices in Germany. Using the parameters of Jan's system as a basis provides a comparison of a realistic implementation in these two locations. Useful comparisons can be drawn from the price of equipment available in these countries, the local codes for adding these systems, and the solar irradiance of these areas. It also allows us to compare the energy rates of the two areas.

Jan's eight panels generated 63 kWh in December of 2025. Using NREL and NASA climate data for Auburn during the same month, a hypothetical generation can be calculated. This data, combined with initial cost and regulations, provides an idea of solar generation in these two cities. While the system would have been able to generate more energy in Auburn, would the less favorable rates make the investment worthwhile?

Both Auburn and Selb have unique advantages for implementing PV systems. Comparing these two gives insight into how these systems are being used in two different parts of the world.

Photovoltaic Safety Hazards and Mitigation Techniques

Adam Bottenfield

As photovoltaic (PV) systems become more integrated into residential, industrial, and commercial infrastructure, unique safety hazards have presented themselves that differ significantly from traditional power systems. This presentation explores the risks inherent in the solar power lifecycle, from installation to decommissioning, and addresses technologies and techniques to mitigate these hazards. A major risk is DC arc flashes — which differ from AC arc flashes in that they lack a zero-crossing point — and the resulting fire risk in building-integrated photovoltaics (BIPV). In BIPV systems, the lack of a ventilation gap between the solar array and the building material can damage the cell and facilitate rapid fire spread behind the modules. Furthermore, the battery storage systems introduce the risk of thermal runaway in Lithium-ion batteries, which requires battery management systems to maintain operation within a safe operating area. The lifecycle of a PV system also presents environmental hazards, specifically the leaching of heavy metals like Lead and Cadmium from modules that reach their end-of-life or suffer structural breakdowns. Beyond chemical toxicity, the high voltage nature of large PV arrays introduces significant electric shock risks inherent in all electrical systems. By analyzing these risks through the lens of current National Electrical Code (NEC) requirements and industry incident data, this presentation outlines the technical mitigations necessary for safe deployment. Key solutions include automated rapid shutdown procedures to protect emergency responders and improved charge controller logic to prevent battery instability. Such engineering interventions are essential to ensure the long-term sustainability and safety of photovoltaic systems.