ASA
ARCHITECTURAL SOLAR ASSOCIATION

Architectural Solar

An Introduction for Building Professionals

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Energizing our Architectures

As the window to mitigate the worst impacts of human-caused climate change rapidly narrows, an essential, once-in-a-generation transformation in energy is underway. At the heart of this transformation are the buildings we occupy. There has never been a greater need for highly integrated, standardized and affordable clean energy systems that leverage our built environment.

Architectural solar is a term that shapes the discussion around solar PV technologies that have architectural significance and integration approaches that are well-coordinated with the architectural design process. Streamlining the deployment of thoughtfully integrated solar generation in the built environment and maximizing the benefits of dual-use solutions that serve as both generation assets and building materials is central to architectural solar. We formed the Architectural Solar Association to drive the widespread adoption of on-site, highly integrated renewables through improved collaboration between the solar and building industries.

The total electricity consumption of U.S. residential and commercial buildings accounts for 74% of our end-use electricity consumption from all bulk electricity generation sources.<source> Industrial sector buildings and sites represent an additional 26% of bulk electricity use. Combined, the residential, commercial and industrial sectors offer a vast decarbonization opportunity for architectural solar, even before we tackle the electrification of site-based fossil fuel combustion and consumption.

Using architectural solar to transform building rooftops, facades, and sites into clean energy generation assets also takes full advantage of source- versus site-based electricity generation. U.S. utility-scale bulk electricity generation from source to load requires an average of 2.8 times more energy than onsite power generation from clean energy sources such as solar.<source> Clearly, where we generate energy is on the same order of importance as how we generate it.

As the principal of a solar design firm and licensed Professional Engineer, I communicate daily with architects, engineers, and construction professionals with deep experience in building design and construction. Frequently, these professionals have limited experience integrating solar generation assets into building projects. Likewise, many solar professionals lack an experienced, well-informed perspective on optimizing solar projects within existing building design and construction workflows. With this in mind, it is not surprising that many of the questions I regularly field are either poorly informed or often the wrong questions entirely. The current disconnect between the solar and building industries often results in non-optimized project workflows, inaccurate performance and financial targets, and missed opportunities.

The first steps in bridging the gap between the solar and building industries are establishing a common design language between stakeholders and developing workflows and tools that inspire collaboration through action. The Architectural Solar Association, in partnership with the U.S. Department of Energy and the National Renewable Energy Laboratory (NREL), has initiated a multi-year effort to develop resources for the solar and building industries that establish a common design language, provide real-world examples of model architectural solar projects, and build foundational principles on designing, financing, and implementing architectural solar for all stakeholders.

The mission of the Architectural Solar Association and its partners is to build a bridge between the solar and building industries and expand how our professional community engages the possibilities of onsite solar generation. In this publication, Architectural Solar: An Introduction for Building Professionals, we present a continuum that illustrates the full spectrum of solar generation opportunities for the buildings and sites we occupy. We highlight real-world, deployed examples that range from site- and building-applied (BAPV) solar arrays to highly-integrated building-integrated photovoltaics (BIPV).

This publication and future resources developed by the Architectural Solar Association will empower architectural, engineering, and construction professionals to unlock the full value of solar in the built environment and enable a broad spectrum of stakeholders to achieve transformative building performance, decarbonization and climate goals.

— Christopher Klinga P.E., Technical Director, Architectural Solar Association

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Introduction

Who We Are

The Architectural Solar Association (ASA) is a 501(c)(6) trade association focused on bringing together the solar and building industries with respect to integrating solar technologies into the built environment. We were formed by a group of industry experts to help expand awareness, act as a supply chain resource and help develop standards associated with solar energy as it relates to architecture. The National Renewable Energy Laboratory (NREL) has decades of focused leadership in clean energy research, development, and deployment. Their team of researchers has partnered with ASA to develop solar educational materials that address the needs of the building industry.

What We Believe

Buildings are the venue of our culture and placemaking. They are central to family, community, education, safety and public health, and business. They are also central to our energy use. Combined, residential, commercial, and industrial buildings account for 99% of electricity consumption in the US <source>. The energy requirements to operate buildings are a function of design and occupant behavior. Modern electrification and decarbonization goals are driving an increase in electricity demand as we transition from fossil to renewable sources of energy. It is crucial to reimagine buildings and their role in our energy consumption to ensure a sustainable future.

Our Vision

We are here to promote the integration of solar technologies into the built environment. Our team envisions a future in which every building and structure leverages its full potential as an energy generating asset to help minimize human impact on the environment.

Our Objectives

- *Educate, equip, and empower architects and building professionals to integrate solar into their workflows.* This initiative includes providing access to resources, training, and support for current and the next generation of construction professionals.

- *Enable the development of powerful financial, climate, and cultural solutions at any building level.* This objective involves advocating for policies and programs that support architectural solar and working with financial institutions and other stakeholders to make integrating solar into buildings easier and more affordable.
- *Enact practical and standardized tools to support innovative designs that leverage energy generation.* This effort requires the development and promotion of design guidelines, standards, and best practices for architectural solar.
- *Establish streamlined interdisciplinary workflows between project stakeholders.* This objective includes breaking down silos between the solar and building industries and developing new ways of collaborating on architectural solar projects.
- *Forge strong relationships between industry, design professionals, owners, and the public to lower barriers to power generation in the built environment.* This goal requires the increased awareness of architectural solar and its benefits and building a coalition of support for its adoption.

What can you do?

- *Learn more about architectural solar.* Read and refer to this guide for your next project. Visit the ASA online or reach out to a member of the ASA team for more information.
- *Get involved.* The ASA is a volunteer-driven organization with many ways to get involved. You can volunteer your time, donate to the ASA, or join the ASA as a member.
- *Advocate for architectural solar.* Talk to your elected officials about the importance of architectural solar, and support policies and programs promoting its adoption.
- *Design with solar in mind.* If you are an architect, engineer, or other design professional, consider how you can integrate solar into your projects. There are many resources available to help you get started.

Together, we can make architectural solar the norm, not the exception. We can create a more sustainable future for all.

Using this Resource

Since the 1970s BIPV has been continuously promised as the next big breakthrough, all while the global solar industry has deployed greater than 1 TW of capacity in the form of rooftop and utility-scale solar. BIPV has remained a niche market but much of this capacity has indeed been coordinated with architecture. Over this time the building industry has been undereducated as the solar industry has evolved and flourished. We believe that the root of the issue is that the solar industry has been born out of a retrofit market opportunity while the design community has been waiting for BIPV to become mainstream. As more and more progressive local governments require on-site solar, the building industry yearns to be educated on technologies that are inevitably showing up in their specifications.

In 2000, Patrina Eiffert, Ph. D and Gregory Kiss had written “Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures - A Sourcebook for Architects,” The intent was to “provide architects and designers with useful information on BIPV systems.” The guide contains 16 projects built between the 1990s and early 2000s. During that time, it was understandable that building professionals gravitated to BIPV when standard solar technologies were nothing more than an eyesore and an afterthought. In recent decades, the solar industry and available solar products has evolved to include a broad range of technologies and means of integration that give building professionals the tools they need to specify best-in-class solutions. There has yet to be a comprehensive publication educating building professionals on solar energy design principles.

This guide provides building professionals with an up-to-date glimpse at the full spectrum of possibilities to empower architectural solar design decisions. We encourage you to use this tool as a reference as you design your next project. Rather than focusing solely on BIPV we see value in the design community gaining an understanding of the complexities of the full spectrum of integration opportunities that are being integrated today. Whether a PV system is on a roof or integral to a wall system, it requires architectural coordination. The coordination skills are directly applicable to the full spectrum of integration opportunities. Lets not let the promise of a robust BIPV supply chain be the reason we fail to act. As the building industry is educated and more architectural solar is deployed, innovative BIPV products will be the inevitable result and hopefully the promise of a robust BIPV supply chain will soon be a reality.

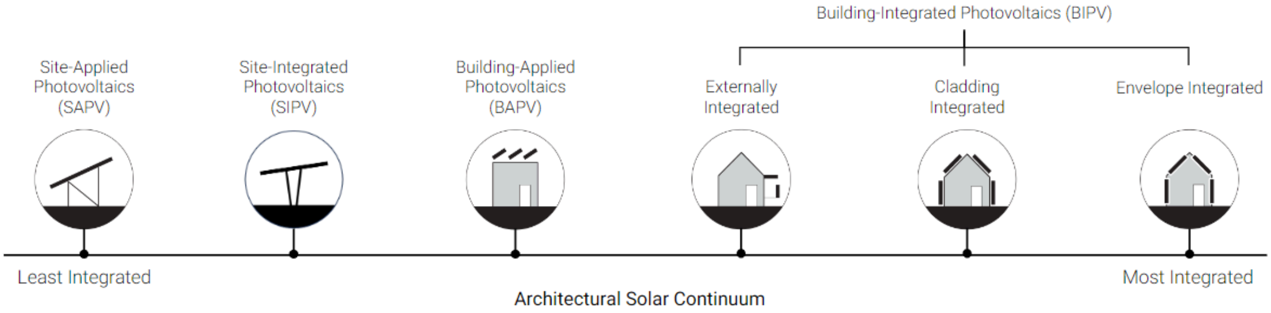
We start this guide by defining Architectural Solar. We will then dig into how solar systems operate, what technologies are available, the configurations of those technologies, and ultimately the Architectural Solar Continuum that includes Site Applied Photovoltaics (SAPV), Site Integrated Photovoltaics (SIPV), Building Applied Photovoltaics (BAPV) and Building Integrated Photovoltaic (BIPV) applications.

What is Architectural Solar?

ASA Defines Architectural Solar as:

Solar energy generating technologies that have architectural significance or are coordinated with the architectural design process.

Architectural Solar is a term that represents all opportunities in which solar energy can be integrated, from ground-mounted solar arrays that are coordinated with the design and construction of a building to a building-integrated photovoltaic (BIPV) curtain wall. Architectural solar exists on a continuum. Considering the full spectrum of integration opportunities empowers design professionals to achieve energy goals while unlocking new potential for the built environment to create clean power, offset energy expenses, reduce peak electrical loads, and provide resiliency.



Solar PV Technology Overview, Components, and Functions

Grid-tied vs. Stand-Alone Systems

Grid-tie solar systems are connected to a public electricity grid. These systems draw power from the grid when onsite solar generation is insufficient and typically export excess energy to the grid. Grid-tied solar is typically net-metered, meaning when the energy is exported the meter rolls backwards. Net-zero energy buildings can rely on the grid to achieve net-zero energy. Solar systems typically produce more energy during the summer months than the winter months. A net-zero building will export energy during most of the summer months offsetting its lower performance in the winter months. When grid power is not available, grid-tied solar turns off to ensure the safety of the grid. If backup power is required, the system must employ battery storage and a means of disconnecting from the grid.

Stand-alone systems, also known as off-grid systems, operate independently of a public electricity grid. The systems are often referred to as a micro-grid because they form their own grid in the event of a power loss. These systems employ battery storage and frequently backup generators to ensure uninterrupted power availability. Stand-alone systems can benefit from being self contained and not requiring coordination with existing infrastructure. For example, stand-alone systems can provide plug-load power, lighting, and charging infrastructure when bringing grid power to a location can prove to be more costly.

Solar Orientation & The Duck Curve

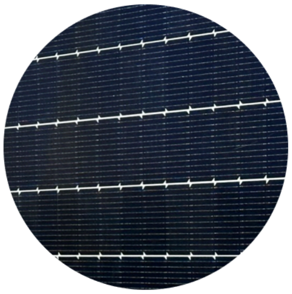
Traditionally solar is designed to maximize yearly energy production. On the most basic level this is accomplished by tilting an array to a site’s latitude and facing it south (in the northern hemisphere). This concept is then balanced by inter-row shading and geometric constraints of the array. Higher tilt angles result in taller arrays that produce larger shadows that require increased inter-row spacing when applicable.

Available solar energy during the day for conventional south-facing installations follows a bell curve that starts at sunrise and ends at sunset. Grid demand varies by location and season but generally it is highest in the early evening during summer months and highest in the early and later parts of the day during the winter months. Unfortunately, this does not coincide with how solar systems are typically designed . As more solar is added to our grids, the net curve results in a more and more pronounced “duck curve” as more electricity is produced during midday sun..

Architectural Solar and storage-based solutions present opportunities to combat this growing concern by introducing methodologies that go beyond maximizing yearly solar production. As the grid evolves, we now more than ever need to think creatively on means and methods that optimize the grid, not just kWh production. Architectural Solar presents that opportunity by integrating solar into the design process of a site or building. By understanding a project's energy profile, designers can tailor a solar array to maximize offset of onsite energy demands. By considering a multitude of tilts and azimuths and storage solutions, designers can broaden the curve and create Grid-Efficient Buildings (GEB).

Crystalline Silicon and Thin Film Technologies

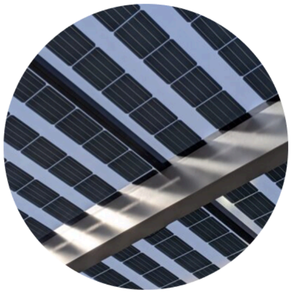
Crystalline



White
Opaque

Black
Opaque

High Density
Semi-Transparent



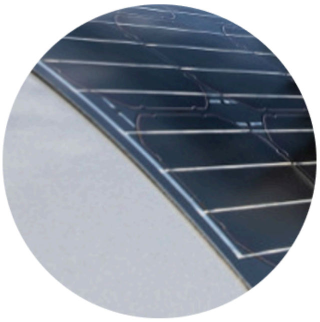
Low Density
Semi-Transparent

The two primary types of commercially available photovoltaic cell technologies are Crystalline Silicon and Thin Film. Solar panels of each technology are composed of solar cells that are electrically connected and packaged for protection from the elements.

The Crystalline Silicon (Si) manufacturing process dates back to the 1950s and underpins all modern electronic technology. The Si manufacturing process yields standalone circular Si wafers cut from a larger cylindrical crystal. Wafers are processed into solar cells and individually laid up and electrically connected into the array seen in solar panels, also referred to as solar modules. Some standard modules are designed to

Thin Film

CdTe
Opaque
Thin Film



CIGS
Opaque
Thin Film

Amorphous Si
Transparent to Opaque
Thin Film

Organic PV
Transparent
Thin Film

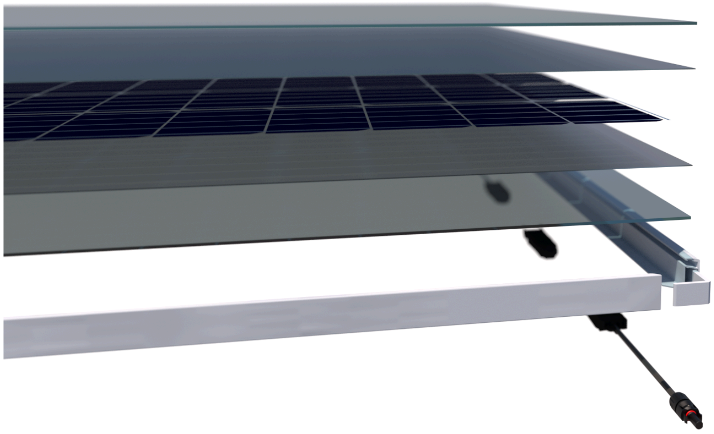
allow light to pass through the gaps between cells. Some manufacturers take this one step further by enabling designers to dictate the arrangement of solar cells in custom patterns that filter light in unique ways, similar to a ceramic frit treatment, a means of painting glass to make it selectively opaque. Many crystalline solar cells today are bifacial and can absorb light on both sides. As manufacturing capacity has increased for these types of solar cells they have reached cost parity with monofacial solar cells. This trend has led to the increased availability of modules that filter light and can be recognized from below, a welcome evolution architecturally.

Thin film solar cells are produced directly on the glass that encapsulates them. The result is a significantly thinner solar cell that is typically about 30x thinner than a Si cell. Historically thin film efficiencies have lagged behind crystalline Si, but Cadmium Telluride (CdTe) modules have approached 20% efficiency and are becoming more cost effective to produce domestically. Some manufacturers offer a range of absorber thicknesses and opacities should designers want to tailor the visible light transmittance to their application. Like the trend in Crystalline Si, thin film modules are composed of two laminated glass sheets, but they are often frameless and may feature proprietary mounting methodologies.

Both c-Si and Thin Film technologies can be Bifacial, meaning they capture sunlight from their front and rear surfaces, enhancing energy yield by utilizing reflected light from nearby surfaces. Bifacial technology optimizes energy generation, particularly in environments with high albedo surfaces, increasing overall efficiency. Both Crystalline-Si and Thin Film modules can be bifacial.

Solar Module Construction

Even when thicker Si materials are used, the majority of the weight of a solar panel is the packaging. Packaging is composed of sheets of glass and/or plastic bonded together with polymer encapsulants and edge-seal to prevent moisture ingress. A junction box is utilized to aggregate the electrical connection on the rear side or edge of the laminate. A frame is often adhered to the package for increased mechanical strength and mounting.



Standard low-iron solar glass typically ranges in thickness from 2–4 mm. Thicker glass results in higher weight modules that are more impact resistant. The commoditized nature of solar modules has pushed solar manufacturers to introduce thinner and thinner glass that enables higher power modules at a lower cost.

Within the built environment, glass thicknesses are typically specified much thicker. Residential glass typically does not get thinner than ⅛” (3 mm), while commercial glass is regularly 3/16” (5 mm) or thicker. Therefore, building-integrated solar glass tends to be thicker than traditional solar glass. This thickness enables it to span greater distances and meet strength and deflection requirements of the building code which tend to be more stringent than the codes that govern common solar modules. The addition of solar cells to glass laminates enables designers to specify solar in a multitude of ways, while the addition of the technology poses negligible structural differences when compared to traditional safety glazing.

Framed versus Frameless Modules

Most standardized solar modules on the market today feature a black or clear anodized aluminum frame that helps control module deflection along its perimeter and adds another degree of weather protection to its edge. Frameless modules are more challenging to mount to standard racking systems and typically require proprietary racking solutions. When specifying frameless modules, one should pay close attention to the compatible racking components. When the racking system is thoughtfully designed in conjunction with a frameless module, installations can be more aesthetically pleasing due to their lower profile and the potential for the racking system to conceal wiring. Several Solar Roofing Tiles on the market today are a great example of frameless technology. Their lack of frame enables them to stay close to the roof and offer superior aesthetics. Overhead frameless modules that are throughbolted provide an unencumbered glass perimeter that can be more easily taped or butt glazed to form a weather barrier. Whereas framed modules typically have clamps to contend with.

When modules are being integrated into a building system that is already designed to accommodate glass laminates, frameless PV modules present many integration opportunities.

Module Power & Efficiency

Each solar module has a corresponding nameplate power rating, which is the direct current (DC) power rating in watts based on Standard Test Conditions (STC), a fixed set of laboratory test conditions. Manufacturers test their modules at these values as a final step in their manufacturing process. PV modules are available in a wide range of power outputs with ratings from a few watts to more than 700 watts for the largest utility-scale solar modules.

Under real-world conditions, operational parameters will vary, and system wiring and power inversion will further reduce the net performance of the solar module. STC Power ratings and the dimensions of a module provide a baseline for comparison of different modules. Modules with a high power per unit of area are more efficient than those with a lower power density. The STC power of a solar PV system paired with location-specific modeling that accounts for solar resource, array tilt and orientation, shading and localized weather characteristics determines an installation's total energy-generation potential. Typically, a module can be expected to perform at about 75-90% of its rated output, depending on deployment conditions. Custom modules with design-specific features can be tailored to the limitations of the glass laminating equipment and the capabilities of the manufacturer.

Standardized versus Customized Products

If specifying a customized solar solution. Standardize module characteristics as much as possible. Standardization can dramatically;

- Reduce project cost
- Simplify warranty replacement
- Simplify O&M diagnostics
- Simplify system design
- Reduce certification complexity

While most solar panels today are standardized solutions, architectural design influences how these technologies are constructed, packaged, and appear. In architectural solar projects, modules may have traditional PV frames, be frameless, or even come on substrates other than glass. They could be flexible. They may be rectangular, square or come in versatile shapes. There are transparent applications of solar where specific wavelengths of light may be absorbed, or the solar is on the edges of the glass.

The architectural industry is less accustomed to standardized products—this is especially true regarding project-specific glass design. As a commercial building material, glass size and performance specifications are often determined on a project-by-project basis to the constraints set forth by a building's geometry. In addition to its physical size, architects can tailor the appearance of the glass selected. Today, solar panels are standardized, commoditized energy-producing products. Various manufacturers offer customizable solar solutions, but the supply chain is less robust than the standardized offerings. When specifying customized solutions, costs should be compared early in the design process to prove feasibility. In some instances, standardized products can be leveraged as building materials, or, at a minimum, customized solutions can be standardized across a project to reduce the number of unique modules.

Color & Opacity

Color & Opacity can be tailored to a project's aesthetic requirements in a number of ways.

Black or Clear Backsheet

The most common method of making a module more architecturally appealing is changing from the traditional white backsheet to either a black or transparent backsheet. The backsheet can be in the form of a flexible polymer or glass. Doing so will give the module an all-black appearance or in the case of a transparent backsheet the ability to filter light in overhead applications.

Glass Screen Printing & Colored Glass

In glass-glass construction the front or rear glass can be screen printed on the internal or external surface of a PV laminate. Treatments with varying degrees of transparency and color can be utilized in front of the solar cells that significantly mask the appearance and only marginally impact the energy potential. Treatments on the rear glass can be utilized to tailor the overall appearance further without substantially impacting the performance of the module.

Colored Interlayers

Colored interlayers can be utilized behind the cells to vary overall transparency or color in the same manner that architectural laminated safety glazing can be customized.

Printed Films

Films offer the ability to customize almost any design that can be imagined. Films are available for the front of the glass that can be applied retroactively or films can be applied to the surface adjacent to the encapsulant if applied prior to the solar manufacturing process. Doing so would require that the film be deemed compatible with the solar bill of materials but it offers the benefit of being encapsulated and away from the elements.

The Architectural Solar Continuum

The Architectural Solar Continuum is a visual, informational guide to the full spectrum of PV applications in the built environment, ranging from least to most integrated. As one progresses across the continuum and the level of solar integration increases, so do the associated multi-functional benefits. Each application type presents a unique set of installed solutions based on project criteria and constraints and the applicability of available products. At its core, the continuum aims to help professionals assess PV integration options to meet project goals, from achieving building energy performance targets to increasing public awareness of sustainability campaigns.

Architects and engineers should seek to integrate solar technologies in a multi-phase approach concurrent with the architectural design process. Within the conceptual development stage, project stakeholders benefit from assessing the project goals related to the available solar resource. The Architectural Solar Continuum enables building professionals to make decisions that empower them to innovate and fully leverage integrated solutions that optimize project outcomes.

The Architectural Solar Continuum includes six top-level categories. We include considerations and benefits of each category, along with real-world examples that highlight a diverse and compelling array of solar generation technologies.

Site-Applied Photovoltaics (SAPV)

Site-applied photovoltaics (SAPV) is the least integrated solar generation category in the Architectural Solar Continuum. While SAPV has a low level of integration, it is considered architectural solar, assuming it is coordinated with the architectural design process or a site's topography, including the use of land and water resources. The value of Site-applied Photovoltaics over utility scale solar is that it is co-located with load. For instance, a site may have adjacent land that lends itself to a ground-mounted solar array. Land that may be underutilized due to zoning restrictions has the potential to make a sizable impact on a building's energy offset. Floating Photovoltaic arrays also known as "Floatovoltaics" present an opportunity to integrate solar with bodies of water that may be underutilized. SAPV at scale presents an opportunity to install solar at a competitive price and optimal yield.

Bose Corporation's 1.7 MW installation in Framingham, Massachusetts is a great example of leveraging underutilized land that is optimal for solar production. Bose's system is designed, owned and operated by Sunpower Corporation. The energy is sold to Bose under a Power Purchase Agreement (PPA). Construction began in 2017 and completed in 2018. Approximately 4.26 acres were required for the 1.7 MW installation. The system is estimated to produce 24,000,000 kWh/year, providing a substantial offset for Bose's corporate campus. <source> /

Site Applied Photovoltaics (SAPV) leverages existing land or an underutilized body of water. Compared to other categories on the continuum, it represents the highest incremental installation cost but requires the least amount of architectural coordination.

Examples of typical SAPV include:

- Fixed-tilt ground-mounted solar arrays
- Single-axis trackers
- Dual-axis trackers
- Floating solar arrays

Depending on the specific technology, a utility-scale solar power plant can require up to 10 acres per megawatt of generating capacity. <Source> Fixed Tilt systems require less land than single and dual-axis tracking systems optimized for higher tilt angles. Though tracking systems take up more space, they have higher energy yields, which may lead to lower levelized cost of energy.

As a point of reference, the fenced area pictured here is 8 acres and supports a 3 MW array with a direct current (DC) capacity of 2.7 MW per acre (8.6 watts/sqft). In comparison, the system pictured on the parking garage is 0.95 acres and supports a 780.3 kW array, yielding MW per acre. (18.76 Watts/sqft)

The floating solar array seen here is 0.57 acres (24,905 sqft) and supports a 249 kW array, yielding 0.4 MW per acre. (~10 Watts/sqft). When dedicating space to ground-mounted or floating solar is not an option, property owners will need to look to opportunities with higher levels of integration and architectural coordination.

Why consider SAPV?

- Maximize on-site energy production and net-zero potential
- Underutilized land
- Lack of space for rooftop PV installations
- Minimum architectural coordination efforts
- Minimize the Levelized Cost of Energy (LCOE)
- Expandable system architecture

SAPV Benefits

- High energy production potential relative to an adjacent building's footprint
- Low cost
- High efficiency installations
- Ease of maintenance (note, some aspects are harder such as landscape management)
- Robust supply chain of standardized products

SAPV Drawbacks

- Poor aesthetics
- Dedicated land use
- High incremental cost
- Vegetation management

Site-Integrated Photovoltaics (SIPV)

Site-Integrated Photovoltaics (SIPV) adds a level of integration to the SAPV category on the architectural solar continuum. SIPV systems provide value beyond just energy production. This value is typically in the form of shade, weather protection, a physical barrier, or brand awareness.

Examples of SIPV include:

- Solar Accessories & Furniture
- Architectural structures
- Agrivoltaics
- Branded installations
- Solar fencing
- Transit shelters
- Parking canopies
- Walkway canopies
- Walking surfaces

SIPV presents an opportunity to reduce complexity and increase energy-generating potential by decoupling solar from a building. SIPV can be more easily installed retroactively and coordinated with new construction since it is less dependent on the constraints of the built environment. Standard commodity or custom solar panels may be used to balance cost and aesthetics. Depending on the site and system design specifications, SIPV can offer high energy production levels per installed area. Covered areas can achieve 15–20 Watts/sqft or more with a range of technologies..

Why consider SIPV?

- Maximize on-site energy production and net-zero potential
- Shading and weather protection for humans, plants, and vehicles
- Lack of space for rooftop PV installations
- Raise awareness of of your sustainability efforts
- Minimize architectural coordination efforts

SIPV Benefits

- Ease of maintenance
- High energy production potential relative to an adjacent building's footprint
- Provides monetizable shade and weather protection

SIPV Drawbacks

- High upfront added material cost
- Water management can add cost and complexity if required
- Groundwork can add risk and complexity
- Creates high visibility messaging opportunities

Solar Accessories and Furniture, such as solar-powered charging stations or outdoor lighting, utilize integrated photovoltaics to charge batteries that bring power to locations that may be costly to retrofit. These structures have the potential to move and adopt different configurations based on changing site constraints. They also provide a level of user interaction that raises awareness of the benefits of solar technologies.

Architectural structures and art installations can seamlessly incorporate photovoltaics. Integrated structures present an opportunity to showcase an organization's commitment to renewable energy while adding aesthetic appeal to urban landscapes.

Agrivoltaics offers an opportunity to co-locate solar and agricultural production, which can increase land use efficiency, reduce water consumption, and increase crop yield for certain species. Agrivoltaics presents a unique dual-use opportunity for an architect or engineer developing a project with an agricultural component. Agrivoltaics can benefit from elevated horizontal arrays, integrated greenhouse arrays, or vertical arrays—such as solar fencing—designed to maximize bifacial gain.

Branded Installations offer an opportunity to showcase a brand's commitment to renewable energy. The University of Miami has integrated branding into a flat roof solar installation via a customizable overlayer with minimal energy yield reduction. Visible from various vantage points nearby and showcased in aerial imagery, this installation benefits from far more than energy production.

In the words of Sistine Solar, the manufacturer of the overlayer, *"These types of installations are the ultimate fusion of art and engineering, of branding and sustainability, of concrete action and powerful storytelling."*

Solar fencing not only enhances security and acts as a sound barrier but also has the potential to harness solar energy. Integrating bifacial photovoltaic panels into fencing systems allows solar power to be generated without occupying additional space. The vertical nature of the arrays has the potential to reduce ground-mounted racking costs and meet site energy demands by converting sunlight into electricity early in the morning and late into the afternoon.

Transit shelters, an essential part of public transportation infrastructure, can now contribute to a greener future. Photovoltaics integrated into transit shelters not only provide shade and protection to commuters but also generate electricity to power lighting, digital displays, and other amenities, reducing reliance on the grid and eliminating the need to route power to sometimes costly and hard to reach locations. In larger-scale canopy applications they offer a great opportunity to grid-tie solar as well.

Parking canopies have become more than just shelters for vehicles; they now serve a dual purpose by simultaneously shading cars and generating clean electricity. Integrating solar panels into these canopies reduces the carbon footprint of parking facilities and provides a source of renewable energy. Parking canopies offer the most significant opportunity for commercial buildings to achieve net zero energy goals.

Patio canopies provide a gathering place where a building's patrons can directly experience the benefits of filtered light from an overhead canopy. Patio canopies are regularly integrated into homes and businesses and are a great solution when desiring both shade and energy production adjacent to a structure.

Walkway canopies take on a new role as they provide shade and protection while capturing sunlight to generate electricity. By incorporating solar panels into these structures, walkways become sustainable power sources, promoting energy efficiency and environmental consciousness.

Walking surfaces can integrate photovoltaic technology, allowing vast areas that receive large amounts of light to generate energy. By transforming walking surfaces into energy-generating surfaces, SIPV can bring about a compelling level of human interaction. Some readily available products today such as those seen here provide an opportunity to engage in a meaningful way. Whether that be via an interactive game or lighting system.

Site-Integrated Photovoltaics presents a world of opportunities where everyday structures and surfaces become agents of change. By harnessing the power of the sun through SIPV in parking canopies, walkway canopies, transit shelters, solar fencing, off-grid accessories, architectural structures, and flooring, we embrace sustainability, reduce our carbon footprint, and create a brighter future powered by clean, renewable energy.

Building-Applied Photovoltaics (BAPV)

BAPV systems are more integrated than site-based deployments on the architectural solar continuum. BAPV systems are installed externally to the building envelope and serve no additional function beyond energy generation. The roof of a building will typically provide an accessible and easily utilizable surface area for solar installations. They also offer the most efficient use of labor during the installation process. Existing walls also present an opportunity. Building attached solar can be classified into two main categories: flush mount or tilt-up and be mounted to any architectural surface.

Why consider BAPV?

- Aggressive energy generation goals
- Maximize savings
- Expansive roof area relatively free of obstacles or obstructions
- Wall area with a surface that easily integrates BAPV

BAPV Benefits

- Lower cost
- Robust supply chain of standardized products
- Less architectural coordination required

BAPV Drawbacks

- Regularly in conflict with poorly coordinated rooftop equipment
- Can require prime rooftop space that may be limited
- Can be subject to high wind loads in comparison to ground mounted arrays
- Can interact with surfaces that have differing warranties or replacement cycles
- Leak potential

Flush mount systems are applied parallel to a roof or wall with a 2-10” gap for wiring and air circulation. The most common installation is on roofs due to their simple installation process, minimal clearance between the roof surface and the back of the module, and their typical location on sloped roof surfaces. Sloped roof surfaces are ideal for flush-mounted solar installations, as the tilt of the roof surface will often increase the energy yield potential of the modules without the need to forfeit space to avoid shading. Various solar racking technologies have been developed for use with a range of different roof types. Relatively smooth textured roof finishes, such as composite shingle roofs, often utilize rails for mounting, where a system of rails is mechanically attached to the roof structure. Integrated clamps secure the modules to the rail system. Ribbed or standing seam metal roofs or walls offer an opportunity to directly mount to their features through the use of specialized mounting equipment, eliminating the need to penetrate the building envelope. Such methods can reduce the risk of unwanted water penetration and reduce installation costs.

Tilt-up systems are the most typical option for flat rooftops but can also be used on sloped rooftops that may not be optimally oriented. Optimizing the tilt of the panels rather than mounting them flush to the roof surface can increase the energy potential of the solar array. It is important to note that increasing the array's tilt angle comes with the expense of fitting less capacity on the roof due to inter-row shading considerations. Tilt-up systems can be mechanically attached, ballasted or use a hybrid approach that combines the two methods. Whereas mechanically attached systems result in holes in the roof to anchor the system, ballasted systems are secured to free-floating concrete blocks that avoid roof penetrations. Since the blocks of ballasted systems increase the dead load on the roof, hybrid systems enable designers to adjust the allowable dead load per the building's structural constraints. The average added dead load of a mechanically attached system is 3 SPF compared to a ballasted system's 10 SPF for a high-wind region.

There are two main types of tilt-up PV systems: Dual-tilt systems, typically placed so panels face east and west with a low tilt angle, such as 10 degrees, to optimize energy density and minimize inter-row shading. The latter is a critical element of the design optimization, as more panels can fit into a flat rooftop area than with single-tilt systems. When these systems are oriented east and west, they allow the system to capture energy through a broader portion of the day. One benefit is the ability to produce power that may align with a utility's higher time of use rates. Single-tilt systems are a more traditional method for flat-roof solar installations. They are typically oriented in a southern direction to maximize overall solar production and are designed to account for shading, with space allocated between the rows. Rather than specifying the optimal spacing and tilt, system designers should first consider pre-configured systems that are more cost-competitive than customizing these details. Racking manufacturers typically offer multiple inter-row spacing options to tailor the array density to the constraints of the building. Striving for wider spacing will increase energy yield per module by reducing inter-row shading, but this may result in fewer modules on the roof, reducing the system's overall energy performance.

Compared to a rooftop canopy with continuous coverage, the constraints associated with BAPV rooftop systems can reduce the energy-generating potential and add warranty risk. Still, they are typically outpaced by the efficacy of the installation process and low-cost installation materials. In some use cases, rooftop PV can meet the net-zero requirements for one and two-story buildings. Rooftop BAPV should also be considered a significant contribution to net-zero goals for taller buildings. As the number of floors increases, the available roof area relative to the floor area significantly decreases, and the relative value of the roof decreases. Typically, in buildings with three or more stories one must look beyond the rooftop to achieve net zero ambitions.

Standardized PV modules can be **wall-mounted** (flush or tilted) as an alternative to roof-mounted arrays. Wall mounting is most easily achieved with metal standing seam cladding, enabling racking systems to clip directly to the structural standing seams. Structural walls can also be used to make a load-bearing connection. Such applications leverage the cost competitiveness of standard commodity modules instead of custom ones. These systems transition from BAPV to BIPV once the solar modules are critical to the wall assembly. Adding this level of integration enables the system to share costs and can increase its cost competitiveness. Tackling this challenge with low-cost, standardized solar modules is a great way to achieve a cost-competitive solution..

Building-Integrated Photovoltaics (BIPV)

BIPV represents the most integrated subset of categories within the Architectural Solar Continuum. It encompasses Externally-Integrated, Cladding-Integrated, and Envelope-Integrated. If solar technology serves a function to a building beyond energy production it is considered BIPV. The importance of the function performed by a BIPV installation can range from improving occupant comfort to preserving life safety.

IEC 63092-Photovoltaics in buildings specifies that BIPV could be used to satisfy any of the following building functions;

- Mechanical rigidity or structural integrity
- Primary weather impact protection: rain, snow, wind, hail
- Energy economy, such as shading, daylighting, thermal insulation
- Fire protection
- Noise protection
- Separation between indoor and outdoor environments
- Security, shelter or safety

Why consider BIPV?

- Appeal of seamless architectural design
- Aesthetic advantage over BAPV installations
- Ambitious energy goals
- Potential for cost savings
- Raise awareness

BIPV Benefits

- Functional dual-use
- Building system resiliency
- Low incremental cost

BIPV Drawbacks

- High level of coordination
- Technically challenging

- Limited supply chain

Externally Integrated BIPV

Externally integrated solar solutions fall within the definition of BIPV under Category E of IEC 63092. They are the least integrated BIPV solution on the architectural solar continuum. Integrating photovoltaic systems into building canopies and awnings can positively impact the energy goals, function, and aesthetic appeal of a building. These structures can serve several purposes by providing coverage and protection to entryways, balconies, patios, exterior stairs, or any unused or underutilized area with sufficient solar access. Canopy structures provide environmental protection to building occupants and outdoor spaces and present the opportunity for high-density solar installations. Solar canopies preserve valuable roof spaces for other valuable programmatic needs, such as outdoor commercial or event spaces and communal spaces like green roofs or pools. From an aesthetic perspective, the customizability of these structures leaves ample room for architectural design freedom. When designing a pergola, for instance, solar technologies with variable solar-to-glass ratios can be arranged in any number of patterns to create the desired lighting and stylistic atmosphere.

Compared to rooftop solar, building-integrated canopies are not constrained by the same access pathway requirements or inter-row shading constraints, typically resulting in a relatively high energy-generating potential. In addition, there are fewer points of contact with a roof’s membrane that may need to be replaced or repaired. Roof replacement and repair should always be considered, and canopies are an easy way to address such concerns. Rooftop canopies can also be extended over underutilized space that rooftop solar cannot necessarily interact with due to possible shading concerns, such as areas above mechanical equipment, elevator bump outs, access hatches, or openings in the architecture. Due to their highly accessible location, maintenance needs are easily met over the lifetime of the system and building. Through their multiple functions and visual draw, these structures symbolize an inspiring commitment to sustainability.

Why consider Externally Integrated PV?

- Already considering integrating awnings or canopies

- Desire to filter light or shade space
- Desire to maximize occupiable space
- System can be optimized for operations & maintenance (O&M)
- More potential for lower cost standardized products than fully integrated custom assemblies
- Mechanical equipment makes rooftop solar challenging
- Leveraging a higher allowable building height in some jurisdictions
- Visual commitment to sustainability

Externally Integrated Benefits

- Dual-use space utilization
- Can be adapted to standard modules or customizable solutions
- Aesthetic appeal
- Shade/weather protection
- Brand awareness/messaging

Externally Integrated Drawbacks

- Balance of System components can be challenging to conceal
- Solar panels can be subjected to meet safety glazing requirements

We break down Externally integrated BIPV into two main subcategories: Shading Elements and Barrier Integrated.

Shading Elements

Shading elements are external structures that provide shade to the building's roof or walls while generating electricity. They also benefit from being adjacent to highly reflective surfaces, which can boost bifacial performance when incorporated.

Building Awnings expand a building's footprint just like an entrance canopy. They are physically attached to the building, increasing their coordination level within the construction process.

In addition to **rooftop and entrance canopies**, buildings may incorporate **long-span superstructures** that span two adjacent building areas or shade the entire roof of a building. **Parking structures** regularly incorporate long-span solutions that can provide weather protection to their top floor, which is a great opportunity to increase a site's energy generating potential.

Horizontal sunshades installed as part of a building's facade can effectively block direct sunlight from entering windows or glazed areas during the high-angle summer sun falling on the façade but allow the low-angle winter sun to provide passive solar heating. By doing so, they optimize solar heat gain, improve occupant comfort, and decrease the need for excessive air conditioning. Integrating solar cells into sunshade glazing or using traditional solar modules instead of a glazing element can help serve the same purpose while generating energy.

Vertical sunshades, commonly referred to as fins, are vertical elements attached to the exterior of a building. Functionally, they create shade from low-angle sunlight and protect against glare, allowing diffused natural light to enter the building. These elements can add architectural directionality, create interesting light and shading interplays, and create texture both on the exterior and for occupants in the interior, all while generating energy. Solar fins can be strategically located and spaced to optimize energy production and shading performance and to correspond with the architectural design.

Incorporating building-integrated solar as shading elements such as horizontal sunshades, vertical sunshades, and double-skin facades presents a range of benefits. These elements provide shade to enhance occupant comfort and generate clean energy while providing numerous benefits like protection from the elements, thermal performance, glare protection, ease of installation and access, architectural articulation, and performance advantages during certain weather conditions or in certain latitudes.

Barrier Integrated Barrier Integrated solar refers to incorporating solar technologies into various types of barriers, such as glass railings and screen walls. This approach offers several benefits. Safety glazing is regularly utilized as a safety barrier. Safety glazing typically comprises laminated glass with a Polyvinyl Butyral (PVB) or equivalent interlayer. A construction methodology that is regularly used within the solar industry. Therefore, solar technologies laminated between two lites of glass with one or two interlayers encapsulating the cells can be classified as safety glazing. Solar glazing elements like this can be incorporated into **glass railings** in the same ways safety glazing is traditionally incorporated. Wires and module termination can be integrated into the framing systems at the handrail or the base and routed in these high-traffic areas. As with many other architectural solar components addressed, solar railing allows an opportunity for stepping and recessing railing elements — referred to as architectural articulation to add visual interest to the space. Designers can choose between many different types of solar glass, ranging from fully transparent to colored or shaded, to those with linear articulation, to those with more of a grid format.

In addition to handrails, **screen walls** offer an excellent opportunity to integrate solar within a barrier. Barriers visually conceal and dampen noise from mechanical equipment on a roof. Such barriers are regularly integrated with architecture, and being adjacent to a rooftop PV system and accessible makes them an easy means of expanding a system's capacity. They can enclose interior spaces, including staircases, and provide interior protection from the elements and sounds. Bifacial technologies can be utilized on rooftops or in exterior applications to increase performance since roof surfaces are typically reflective, and vertical east and west-facing modules can receive direct sunlight from each side.

Double-skin facades are a version of Barrier-integrated BIPV that require more architectural coordination and serve a vital role in the thermal design of the building. Double-skin facades consist of an outer layer and an inner layer of glazing, creating an air gap or cavity between them. Air can be an excellent insulator when properly contained. Using a double-skin facade, the designer created thermal insulation, limiting thermal bridging and solar heat gain into the interior, reducing glare, and creating soundproofing benefits. The exterior facade, where the solar PV is located, captures sunlight that would otherwise reach the building's interior, converting it into usable energy for the building. These double-skin facades are typically designed to maintain access between the two facades, allowing for ease of installation and maintenance over the lifetime of the solar-integrated building components. These can also be designed to direct rain and snow to specific areas around the exterior of the building, serving as a buffer against the risks water can pose to buildings, such as mold, decay, corrosion and structural risks, and soil expansion.

Barrier-integrated solar, including guardrail-integrated, screen wall-integrated systems, and double-skin facades, offers space efficiency, renewable energy generation, enhanced safety, noise reduction, aesthetic appeal, cost savings, thermal performance, and contributes to sustainability efforts.

Cladding Integrated BIPV

Cladding elements are externally integrated as an assembly integral to enclosing the building envelope. They fall within the definition of BIPV under Categories A and C of IEC 63092. Cladding elements are typically components of a roof or wall assembly and can serve as a primary or secondary weather barrier. Roof-integrated cladding offers the best energy production opportunities. Still, wall systems can provide increased energy generation potential and are a significant next step in expanding beyond the rooftop, especially for buildings with more than two floors.

Why consider Cladding Integrated PV?

- Already considering integrating a cladding system
- Appeal of seamless architectural integration
- Ambitious energy goals

Cladding Integrated Benefits

- Application of high efficiency opaque products
- Aesthetic appeal
- Low incremental cost when offset by typical wall or roof system costs
- Integrating solar typically results in leveraging glass as a more durable building material

Cladding Integrated Drawbacks

- HIgher upfront cost
- Smaller module form factors can increase installation costs and system connections
- Challenging O&M accessibility
- Higher operating temperatures
- Trade coordination required
- Limited supply chain

Roof Cladding Integrated

Roof-integrated solar consists of elements that function as primary or secondary weather barriers. Such elements include **Solar Roof Tiles**, also known as **Solar Shingles**, **Solar Module Roof Systems**, **Solar Flooring** or decking, and **Adhered Flexible Modules**. A significant benefit of these systems is that they can enable incremental installation labor savings <source> and potential added tax savings in some instances. For instance, if a new roof is being planned and a solar roof is substituted, the cost of the new roof can be subtracted to obtain the incremental cost of solar. This incremental cost has the potential to be less expensive than traditional BAPV solar <source>. By analyzing the financial return of the incremental cost with the full benefit of potential tax credits, solar of this type can quickly be realized as an equivalent or less costly installation compared to traditional BAPV technologies.

Solar Roof Tiles, also known as solar shingles, offer numerous benefits when compared to traditional solar panels. Their main advantage is appearance due to their seamless integration. Some shingles may also utilize space more efficiently by integrating closer to hips and valleys than larger solar modules. They also tend to be mechanically more durable because of their smaller sizes, which reduce glass deflections and risks of cell damage. For this reason, some solar shingles can be walked on, enabling increased roof access and maintenance.

Solar Module Roof Systems leverage the commoditized nature of standard solar module form factors and integrate them to make the panels a true weather barrier. This typically consists of building up a substructure to support the solar modules above the roof deck, flashing the upper edge of the array, sealing module gaps, and finishing the perimeter of the array with a flashing that sufficiently manages water intrusion. Such systems typically utilize all-black modules for their appearance and strike a balance between aesthetics and the cost effectiveness of larger solar modules.

Solar Flooring typically needs to occur on a roof, whether a balcony or a flat roof. Solar flooring systems serve the same purpose as a raised deck. They manage water by letting water drain between each tile to the primary roof surface below. Wiring can be routed as the tiles are installed on a similar structure to those utilized with concrete roofing tiles.

Such systems are a great way to increase the energy-generating potential of a roof that is typically unoccupied and in full sun.

Adhered Flexible Modules can be pre-adhered to metal roof panels or installed in the field. Once adhered, they become integral to their substructure, which serves as their means of de-installation. Their flexible nature enables them to adhere to curved surfaces more aesthetically than most technologies.

Wall Cladding Integrated

An exterior wall can consist of Wall-Mounted solar modules (BAPV) or be considered more integral as an **Exterior Wall Assembly**. Wall Mounting standard solar modules offer a means of leveraging the low cost of standard solar modules as building components. They could be considered integral to the exterior wall assembly in certain well-coordinated instances. Doing so requires coordination of the mounting system, and not all racking systems are well suited for a vertical installation process. As the market evolves to enable more cladding systems to work with more solar manufacturers, more exterior wall assembly-integrated systems will become more prevalent

Envelope-Integrated BIPV

The Envelope Integrated category consists of solar technologies that form a physical barrier between the conditioned and unconditioned environment of a building. Envelope integration leverages the cost of the envelope installation that would occur regardless of whether solar integration was being considered.

Why consider Envelope Integrated PV?

- Already incorporating a glazing system
- Appeal of seamless architectural integration
- Ambitious energy goals
- Considering a frit treatment or tint for bird safety, glare or heat gain reduction.
- Considering the added sound protection of laminated glass

Envelope Integrated Benefits

- Aesthetic appeal
- Reduction in Solar Heat Gain
- Noise reduction
- Longer life components
- Low incremental cost when offset by typical wall system costs

Envelope Integrated Drawbacks

- Difficult to coordinate multiple specialized trades
- Balance of System components can be challenging to conceal
- BIPV and adjacent Non-BIPV varying IGU thicknesses
- Costly and difficult to coordinate wire management
- Limited supply chain and atypical procurement process
- Lack of code guidance
- May require UL field certification

Envelope-integrated BIPV typically integrates solar technology into an insulated glass unit (IGU) because an IGU is typically required to separate conditioned space from the outdoors to meet energy code requirements.. IGUs that feature photovoltaics are generally referred to as **PV-IGU's**. PV IGU's typically integrate solar cells within an outboard glass laminate or on an individual outboard lite.. This can be accomplished a number of ways. 4 methodologies can be seen in the rendering below.

- Outboard Laminate with Crystalline-Si cells laminated within.
- Thin-Film technology applied to surface 2 of an outboard lite.
- Thin-film technology applied to surface 2 of an outboard laminate
- Thin film technology applied to the first surface of an annealed lite that is centrally located within an outboard laminate.
  - Thin-film technologies are susceptible to roller wave distortion which is typically more pronounced in tempered glass. This is one reason why tri-laminates have proven to be popular with various thin-film suppliers. The tri-laminate configuration also enables smaller glass lites to be integrated into larger laminates multiple times. Increasing the range of compatible sizes.

Close attention should be paid to the overall PV-IGU thickness as it compares to adjacent non-PV glass. Varying IGU thicknesses can cause coordination challenges when integrating with off the shelf wall systems. In addition, junction box integration is a detail that can dictate what wall systems are compatible with PV-IGUs. Design professionals should seek to understand the junction box details, the process in which they are integrated within the framing and the constraints that they will impart.

An alternative methodology utilizing a film on an outboard lite directs light into **perimeter integrated solar cells** of an IGU as depicted below.

Envelope-Integrated Glazing typically benefits from solar acting as a shading element to directly reduce solar heat gain. Doing so with crystalline technologies allows for light filtering and creating unique textures within a space.

Today, there are readily available thin-film technologies that allow for various degrees of tint corresponding to respective levels of efficiency. Generally speaking, as technologies become more opaque, their efficiency increases. Two benefits of thin film technologies over crystalline technologies are that they perform better at higher temperatures and have increased performance under low light conditions, two conditions present in BIPV applications. These benefits hold promise in the fact that lower efficiency high transparency technologies have potential to be applied across large amounts of unused surface area.

Sloped Glazing applications like the one pictured here offer the best opportunity to optimize orientation for energy production. Overhead applications also are less prone to occupants scrutinizing the visual appearance of semi-transparent or semi-translucent technologies.

Vision Glazing applications offer the best opportunity to penetrate large glass areas.

Architectural vision glass regularly features frit, an opaque ceramic coating fused to the glass surface to reduce glare or solar heat gain by directly blocking light in the form of a pattern or continuous opaque surface.. Solar cells can be tailored to provide the same reduction in Visible Light Transmission (VLT). Various thin film products are available to meet a varying degree of transparency and Crystalline-Si products enable designers to tailor cell layouts to benefit their project specific needs.

Spandrel Glazing offers the best opportunity for high-efficiency technology because it is typically opaque. Its purpose is to span floor partitions or columns or wall partitions that are to be concealed from the exterior. In the instance seen here the opaque spandrel is backed by a wall cavity that enabled wiring to be routed from floor to floor to aggregate wiring that ultimately traveled back to the electrical rooms that were centrally located within the building.

A Path to Widespread Adoption

Architectural solar is a rapidly evolving field with the potential to transform our built environment from energy sinks into a sustainable energy resource. While our building stock is still far from self-sustaining, several powerful forces are driving us toward a path to sustainability:

- *Declining costs of solar PV:* The cost of solar PV has fallen dramatically in recent years, making it one of the most economical energy solutions available in many regions worldwide.
- *Increasingly sustainable building codes:* The AIA 2030 Challenge, the SE 2050 Commitment, and the Living Building Challenge are all examples of voluntary building codes and standards that promote using renewable energy in buildings.
- *Adoption of decarbonization and electrification goals:* Many cities and states have adopted decarbonization and electrification goals, which drive the demand for renewable energy, including architectural solar.
- *Government incentives:* Governments worldwide are offering incentives to promote the adoption of renewable energy, including architectural solar.
- *Technological innovation:* New technologies and products are constantly being developed to make architectural solar more efficient, affordable, and aesthetically pleasing.

Despite these positive trends, some barriers exist to the widespread adoption of architectural solar. These include:

- *Lack of awareness and understanding:* Many architects, engineers, and construction professionals are not fully aware of architectural solar's benefits and potential applications.
- *Soft costs:* The soft costs associated with designing and installing architectural solar systems can still be significant.
- *Fragmented industry:* The architectural solar industry is still relatively fragmented, making it difficult for building owners to find qualified professionals and contractors.

To overcome these barriers and achieve widespread adoption of architectural solar, it is essential to:

- *Educate the industry:* Architects, engineers, construction professionals, and building owners need to be educated about the benefits and potential applications of architectural solar. This can be done through workshops, seminars, and other educational programs.

- *Reduce soft costs:* The soft costs associated with architectural solar systems must be reduced to make them more affordable for building owners. This can be done through education, standardization, innovation, and other efficiency measures.
- *Integrate the industry:* The architectural solar industry needs to become more integrated to make it easier for building owners to find qualified professionals and contractors. This can be achieved through partnerships, collaboration, and other initiatives between the solar and building construction industries.

The widespread adoption of architectural solar offers a number of benefits, including:

- *Reduced energy costs:* Architectural solar systems can help building owners reduce their energy costs by generating electricity on-site.
- *Reduced environmental impact:* Architectural solar systems can help to reduce greenhouse gas emissions and other forms of environmental pollution.
- *Increased property value:* Architectural solar systems can increase the value of buildings by making them more sustainable and energy-efficient.
- *Job creation:* The architectural solar industry is expected to create millions of new jobs in the coming years.

Overall, the future of architectural solar is bright. With continued declines in costs, technological innovation, and government support, architectural solar is poised to become a mainstream market segment in the years to come. Solar energy should be seen as a tool to innovate rather than a constraint to adapt to. We hope that the broad continuum of integration opportunities presented here provides insight into all that is possible.

Acronyms

Architectural Solar Association (ASA)

Balance of System Equipment (BOS)

Building-Applied Photovoltaics (BAPV)

Building Information Modelling (BIM)

Building-Integrated Photovoltaics (BIPV)

Environmental, Social and Corporate Governance (ESG)

Grid-Efficient Buildings (GEB)

International Electrotechnical Commission (IEC)

Internal Rate of Return (IRR)

Insulated Glass Unit (IGU)

Net Present Value (NPV)

National Renewable Energy Laboratory (NREL)

Operations and Maintenance (O&M)

Photovoltaic (PV)

Site-Applied Photovoltaics (SAPV)

Site-Integrated Photovoltaics (SIPV)

Standard Test Conditions (STC)

U.S. Department of Energy (DOE)

U.S. Energy Information Administration (EIA)

Technical Advisory Group (TAG)

Glossary

Architectural Solar — Solar photovoltaic energy generating technologies that have architectural significance or are coordinated with the architectural design process.

Agrivoltaics — The integration of solar energy generation on agricultural sites that benefit from the installation beyond energy production.

Antireflection Coating — a thin coating of a material applied to the surface of a photovoltaic cell that reduces light reflection and increases light transmission into the cell.

Awning — Overhung shading mechanism, usually found over a window, door, or entrance.

Balustrade — A balustrade is a railing supported by balusters, typically forming a protective barrier along the edge of a balcony, staircase, or terrace. Balusters typically provide vertical structural support and aesthetic appeal for a balustrade system.

Balance of System (BOS) — Non-PV components of a photovoltaic system that typically includes wiring, switches, power conditioning units, meters, and battery storage equipment (if required).

Bifacial Modules — A two-sided solar module where both the front and back have power-generating capacities. The power generated by the back side of the module is often referred to as bifacial gain.

Building Applied Photovoltaics or Building Attached Photovoltaics (BAPV) — Photovoltaic systems applied or attached to a building by means of a method that does not add value to the building beyond energy production.

Building-Integrated Photovoltaics (BIPV) — -Photovoltaic systems integrated into a building by means of a method that adds value to the building beyond energy production as per the requirements of IEC 63092.

Carbon Footprint — The negative impact imposed on the environment by an object or person as measured by emission of greenhouse gasses (carbon dioxide and methane).

Curtain Wall — an exterior wall that provides no structural support.

Decarbonization — the reduction of greenhouse gas emissions by revolutionizing the current fossil-fuel-reliant energy industry to one powered solely by renewable and low-carbon energy sources.

Distributed Energy Resource (DER) - Energy generation and storage sources interconnected in parallel with a utility's grid where energy is consumed.

Encapsulant — Plastic or other material around PV cells that hold module materials (glass, backsheets) together to create a package protects them from environmental damage.

Envelope — The basement walls, exterior walls, floor, roof and any other building elements that enclose conditioned space or provide a boundary between conditioned space and exempt or unconditioned space.

Facade — The side or face of a building.

Flashing — thin material or membrane that prevents water from permeating the structure by protecting joints and intersections.

Glazing — transparent material (such as glass) used for windows.

Grid-Connected — Tied with an electric power utility. Systems typically include a PV array, an inverter, and various Balance of System (BOS) components.

Grid-Interactive Efficient Building - Buildings that are efficient, connected, smart & flexible as they interact with a utility grid.

Inverter — Device that transforms direct-current (DC) electricity from a solar panel to alternating-current (AC) electricity.

Lites (of glass) — individual panes of glass within a panel.

Low-e glass — low-emissivity glass with higher thermal performance.

Maximum Power Output — The performance of PV modules and arrays according to their maximum DC power output under Standard Test Conditions (STC).

Module — Commercial PV product containing interconnected solar cells; modules come in various standard sizes and can also be custom-made by the manufacturer.

Net Zero Energy — when the balance of energy for vehicles, thermal, and electrical energy within the site boundary is met by renewable energy.

Parapet — a low protective wall or barrier at the edge of a roof, balcony, or terrace, providing safety and architectural aesthetics.

Photovoltaic (PV) — *Photo* meaning *light* and *volt* meaning electromotive force, *photovoltaic* is the transformation of light into electrical power.

PV Array — Group or string of connected PV modules operating as a single unit

PV Solar Cell — Device made of semiconductor materials that converts direct or diffuse light into electricity; typical PV technologies are made from crystalline, polycrystalline, and amorphous silicon and other thin-film materials.

Renewable Energy — Renewable energy uses energy sources that are continually replenished by nature—the sun, the wind, water, the Earth's heat, and plants. Renewable energy technologies turn these sources into usable forms of energy—most often electricity, but also heat, chemicals, or mechanical power.

Roof Membrane — a thin material that protects the upper part of a building from air and water permeation; flashing is part of a roof membrane.

Screen Wall — A wall used for protection or privacy which supports only its own vertical weight.

Shading, Inter-row Shading — shading on a solar panel is detrimental to its power output and efficiency. Inter-row shading is the incident shade of a row of solar panels onto the next, which is an important design consideration.

Site-Applied Photovoltaics (SAPV) - Photovoltaic systems applied to a site by means of a method that does not add value to the site beyond energy production.

Site-Integrated Photovoltaics (SIPV) -Photovoltaic systems integrated into a site by means of a method that adds value to the site beyond energy production.

Soft Costs — Non-hardware costs, including permitting, financing, installation, and the expenses solar companies may incur to acquire new customers, pay suppliers, and cover their bottom line. For rooftop solar energy systems, soft costs represent the largest share of total costs.

Spandrel — building component that serves as spacing between sections of vision glass (meant to be see-through) and attached to the frame/structure of the building. It can be made of glass or other materials such as composites.

Stand-Alone — Remote power source separate from an electric utility grid; a stand-alone system typically has a battery storage component.

Solar Generation — Energy generated by means of solar technology.

Watt — Unit of power abbreviated as W. A kilowatt (kW) is equal to one thousand watts

kWh — The kilowatt-hour (kWh) is a unit of energy equal to 1,000 watt-hours or 3.6 megajoules. The kilowatt hour is the most common billing unit for energy delivered to consumers by electric utilities.

References

1. *Last Name, First Initial.; Last Name, First Initial. “Title : Subtitle.”, Publisher, City, State: (Year), page if applicable*

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3.

About the Participants

ASA

The Architectural Solar Association (ASA) represents a growing industry with an overarching goal of transforming architectural surfaces into generating assets. We were formed to help expand awareness, act as a supply chain resource and help develop standards associated with solar energy as it relates to architecture.

NREL

NREL has decades of focused leadership in clean energy research, development, and deployment. From work in basic sciences to systems engineering and analysis, all of its researchers are focused on solving market-relevant problems that result in deployable solutions. Their partnerships ensure work is relevant and applicable to the energy problems that people are trying to solve. They are the trusted clean energy leaders, and their work will guide the nation in achieving ambitious goals in reducing greenhouse gas emissions and a decarbonized clean energy future.

Solar Energy Technologies Office (SETO)

The U.S. Department of Energy Solar Energy Technologies Office accelerates the advancement and deployment of solar technology in support of an equitable transition to a decarbonized economy. Learn more at energy.gov/eere/solar.

Building Technologies Office (BTO)

The U.S. Department of Energy Building Technologies Office (BTO) develops, demonstrates, and accelerates the adoption of cost-effective technologies, techniques, tools and services that enable high-performing, energy-efficient and demand-flexible residential and commercial buildings in both the new & existing buildings markets, in support of an equitable transition to a decarbonized energy system by 2050, starting with a decarbonized power sector by 2035. Learn more at energy.gov/eere/buildings.

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Chris serves as the Technical Director of the Architectural Solar Association, and holds a B.S. in Mechanical Engineering from the University of Colorado in Boulder, CO. He is a licensed, professional structural engineer and has been designing solar products and projects since 2007. In addition to his efforts with ASA, Chris operates SolMotiv Design, a solar engineering firm focused on the design and integration of solar technologies within the built environment.

Stan Pipkin, Architect, Solar EPC, Consultant

Since 2007, Stan has co-managed and owned Lighthouse Solar in Austin, TX. He has been involved in the shaping of local and state policy to foster the growth of solar energy, and runs an architectural design practice, Pipkinc., focusing on residential, commercial and civic projects. While managing and growing all aspects of Lighthouse Solar, Stan worked closely with a number of industry innovators, including Lumos Solar on the development of its architectural solar product suite. Stan holds a Master of Architecture from the University of Texas, and his skill-set sits at the nexus of solar energy and architecture.

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Over three decades, Joe has employed strategic planning, business development, team building, communications, content creation, learning design, grant writing, and curriculum development to accelerate our transition to a clean, renewable, and just energy future. He assembled and led the exceptional team that launched and published SolarPro, the U.S. solar industry's bar-setting trade publication. Joe works side-by-side with clean energy non-profits and corporates to set and achieve transformative business and decarbonization goals.

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