DOE | Building Integrated Photovoltaics

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1.0 INTRODUCTION

In recent years, a number of building integrated photovoltaic (BIPV) elements—such as integrated rooftop solutions, solar shingles, facades, canopies, PV windows, and PV glass product offerings—have entered the market, and these solutions appear to be quite promising from a technical capability and performance perspective. Investments in research and development have led to the creation of BIPV materials and elements that work. The outlook for the BIPV market has been, and continues to be, optimistic. According to a recent analysis from BCC Research, the global market for BIPV is forecast to increase from approximately $4.558 billion in 2021 to $11.269 billion in 2025.[1] With this said, the United States has yet to witness the widespread adoption of BIPV, particularly in the residential and commercial segments. The Department of Energy's Solar Energy Technologies Office would like to better understand this problem and the various hurdles hindering BIPV adoption. The purpose of this report is to provide insight into a subset of questions that are of interest to the Solar energy Technologies Office, including:

- What factors are impacting market growth and adoption of in BIPV?
- How large is the BIPV market by revenue and capacity?
    - It seems that the European and Asian markets for BIPV are more robust than the BIPV market in the United States, and BIPV is being implemented more often in newly constructed buildings in Europe and Asia. Why might this be?
    - How have the different countries or regions embraced BIPV and what policies and incentives are in place to drive technology adoption?
    - How do the European and Asian markets compare to the U.S. market, in terms of similarities and differences?
- There are a number of key stakeholder groups influencing BIPV adoption, including builders, construction companies, and architects, among others. Which stakeholder groups are champions for BIPV?
    - Is any particular group pushing for BIPV integration in new buildings?
- What is the nature of the relationship that exists between roofers, builders and solar installation companies?
    - What factors draw these groups together?
    - What factors are keeping them apart and perhaps hindering collaboration?
- Without sophisticated models and an accurate estimate of system energy yield, it is difficult to ascertain the relative advantages and disadvantages of the various BIPV technologies versus photovoltaics, more broadly.
    - What are the best-in-class tools for modeling complex PV/BIPV projects where shading and reflections may be likely to impact system performance?

Both primary and secondary market research were conducted to address the questions of interest.

2.0 BIPV Market

Image Source: 51st Japan National University Championship, Before a Game, 2015. [Wikimedia Commons](#).

2.0 BIPV MARKET OVERVIEW

The global market for BIPV is growing and the industry is seeing the increasing adoption of BIPV elements. However, the European and Asian markets seem to be more robust than the U.S. BIPV market. This section discusses the global BIPV market dynamics including advantages and disadvantages of the technologies, and factors influencing its adoption in the U.S. and in other areas.

2.1 INTRODUCTION TO BIPV AND BAPV

The Solar Energy Industries Association (SEIA) discusses BIPV, noting that building integrated photovoltaics are dual purpose, serving as both the outer layer of the structure and generating electricity (either for on-site use or to export energy to the grid). BIPV systems can "provide savings in materials and electricity costs, reduce pollution, and add to the architectural appeal of a building."[2] While BIPV technology can be added as a retrofit, BIPV systems maximize their value when they are included as part of the initial building design. By substituting BIPV for standard materials during initial construction, "builders can reduce the incremental cost of PV systems and eliminate costs and design issues for separate mounting systems."[3]

BIPV systems are planned during the architectural design stage and the PV technologies (which may include PV rooftops, facades, and glazing applications such as windows and skylights) are added during the initial construction of the home or building. Closely related to BIPV is BAPV—or building-added photovoltaics. BAPV is planned and built during a retrofit.[4] There are environmental factors that may influence the degree to which a building can benefit from BIPV (or BAPV)—some buildings are more suitable for BIPV than others. Insolation, climate and weather conditions, shading, and latitude can all impact PV system output.[5]

BIPV encompasses a range of solar PV technologies, including roofing materials, facades, and solar PV windows and glass, among others. This section provides an overview of the BIPV market and the various application segments within the market, as well as further commentary regarding viable opportunities for growth and adoption in the BIPV segment.

2.1 ADVANTAGES OF BIPV

When exploring the advantages of BIPV over other materials aesthetics surfaces as an advantage and disadvantage. While aesthetics is very much a concern—and in many cases, it continues to be a significant hurdle for BIPV adoption—some sources acknowledge that BIPV offers a better aesthetic compared to traditional solar PV panels. BIPV technologies such as solar shingles, solar skins, glazing, and solar fabrics are more attractive to architects, builders, and home or building owners because they can more easily blend in with the design of the home or building. Reaching a "middle ground between aesthetics and functionality is crucial for solar roofing to break into a broader market."[6] For example, solar shingles are designed to look like traditional asphalt shingles. They protect the roof and offer the same durability and flexibility as regular shingles, while simultaneously harnessing solar power. Solar shingles are more aesthetically pleasing compared to more obvious solar panels. They can also be removed and reinstalled if the owner of the home wanted to move.[7]

While solar shingles are currently costly, compared to solar panels, it is worth noting that a full roof replacement is not always necessary (this may depend on the brand of solar shingle). If a homeowner or building owner wanted to install a few solar shingles, that is something that can be done. While solar shingles may be an investment, it has been demonstrated that homebuyers are willing to pay up to $15,000 more for a home with solar roofing features.[8] In situations where a new roof or a roof expansion is already planned, solar tiles may actually achieve a lower cost than a normal roof and solar panels combined (this is not always the case, but it is possible).[9]

Solar shingles also offer advantages pertaining to energy cost reduction. Solar roof shingles can reduce annual energy costs by 40-60%.[10] Home or building owners that install solar shingles will quality for the federal solar tax credit.[11] Holes do not have to be drilled through the roof shingles, as they would for installing solar PV panels.[12] All of these factors have been identified as advantages to BIPV—and solar roofing, in particular.

According to a report from the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and Becquerel Institute, factors supporting the use of BIPV technologies include a decrease in manufacturing costs for such solutions, increasing product performance, growing regulatory and social pressure to implement renewable energy technologies and reduce the environmental footprint of buildings, and the fact that current BIPV products can be highly customized and introduced to the construction sector as conventional elements.[13]

2.2 DISADVANTAGES OF BIPV

While the advantages of BIPV are clear, it can sometimes be more difficult to tease out all of the hurdles and barriers to BIPV adoption. It appears there are a number of challenges facing the BIPV segment. Many of the challenges discussed today focus on solar roofing products, as this is currently the largest segment of the BIPV market. According to BCC Research, it is estimated that the roofing segment currently accounts for an 81% share of the American BIPV market.[14]

While there are a few disadvantages to using BIPV, one major disadvantage cited in a number of sources was cost. Solar shingles are more expensive than conventional panels, making panels a more affordable solution for some builders and owners.[15] According to one source, the average roofing installation price for a solar shingle roof can cost between $60,000 to $75,000 depending on the slope, pitch, and size of a roof. Builders or homeowners can expect to pay approximately $21-$25 per square foot, or $2,100-$2,500 per square installed on a standard size single story home.[16] Another source looks at a Tesla solar roof and compared it to the cost of a traditional roof replacement with a conventional 10 kW solar system added—it was estimated that a traditional roof replacement for a 1,700 square foot roof would cost approximately $9,350. If the homeowner wanted to add solar (conventional 10kW solar system) to a conventional roof, that system would cost an additional $24,900—for a total of $34,250. A Tesla solar roof for the same home (assuming simple roof complexity) would cost approximately $43,900.[17] The total cost to install solar shingles are about three times the cost of conventional roofing materials (this is after the existing 26% solar tax credit).[18] Many brands of solar shingles cost more than the average cost of solar panels in the United States.[19]

Another issue with solar shingles pertains to energy efficiency. Solar shingles are sometimes less energy efficient than regular solar panels and the building will require a particular roof slope with high sunlight exposure.[20] Traditional solar panels can produce more energy per watt in comparison to the cost of solar installation.[21] Solar shingles may also have a shorter lifespan. The average solar panel lasts from 20-30 years at maximum energy output. Solar panel shingles will continue to produce solar power after the 20-year mark; however, their performance may start to degrade and they may not produce energy at maximum capacity as they originally did when they were first installed.[22] The orientation of the roof is an important factor influencing the output of solar shingles. Rack-mounted rooftop solar panels can be installed at angles to capture maximum sunlight, but solar shingles are at the mercy of the direction, pitch, and orientation of the roof. They tend to produce less energy because of this factor.[23]

In an existing building, one of the primary disadvantages of solar shingles is having to remove parts of the roof to install them.[24] While some brands of solar shingles will enable home or building owners to replace some shingles and not all, there are some technologies (such as Tesla solar shingles) that would require a full roof replacement. In cases where only some of the roof shingles are replaced with solar shingles, the aesthetic issue that exists with regular solar panels will be present with solar shingles, as well.[25]

The installation of solar shingles and other solar roofing products can be complicated, a factor that is giving roofing companies pause when it comes to promoting these technologies. No two roof systems are exactly identical and roofers need to be able to cut and customize their roofing materials on-site to obtain the perfect fit. Solar cells have a specific structure and the shingles cannot be easily cut or altered on-site (if they can be altered at all).[26]

How solar shingles capture energy from the sun is another concern for roofing contractors and, one would assume, builders. Solar energy is captured in DC power, but a house and the utility grid run in AC power. Traditional solar system can invert the DC power to usable AC power. There are two main ways to accomplish this task. The first way is to join all the panels on the roof together as one unit and wire everything into a single central inverter. This issue with this approach is that the inverter focuses on the lowest common denominator for its power production, so if a homeowner has a string of 20 solar panels, they all reach the level of production of the weakest panel. This can be an issue on cloudy days, as one panel in the shade will drastically reduce the performance of all other panels. The vast majority of roofs will have at least some part of the roof shaded all day long, so a central inverter may not be practical for a solar roof. The second way to invert DC power to AC power is to have a single inverter on every panel. This is referred to as a micro-inverter. There is no loss in power due to other panels being shaded. However, most solar shingles measure about 1-3 square feet, which would mean that a typical roof would require hundreds of panels—and hundreds of micro-inverters. This would substantially increase the cost, to the extent that the solution would largely be impractical.[27]

While some BIPV solutions, such as Tesla's solar roof shingles, have been praised from an aesthetic standpoint—they look similar to traditional roof shingles, compared to solar PV panels—aesthetics is still cited as one of the most significant barriers to widespread BIPV adoption. Solar companies focus on maximum efficiency, but builders want products that are both functional and aesthetically pleasing. While designs are improving and BIPV companies are making strides in developing solutions that blend into the building, industry experts are still citing appearance as the main reason why BIPV has struggled to gain acceptance. On top of this issue—there is a significant cost premium. These factors together have made it challenging for the BIPV market to pick up.[28] Other sources echo this sentiment, noting that solar shingles are limited to just a few styles and designs. For architects and owners concerned about aesthetics, this can be a barrier to adoption.[29]

Many solar installers do not offer solar shingles yet, as this technology is relatively new and still growing in terms of adoption.[30] Builders are also cost-sensitive and this can be an issue for BIPV technology adoption, as buy in from builders would be helpful for commercialization. Many residential construction companies opposed California's requirement for solar on most new homes because of the additional expense (even though solar will ultimately pay for itself over time).[31]

These barriers to adoption are not only seen with roofing products and solar shingles—they are also seen with windows and other glazing applications. One downside to glazing is that it is not as efficient of a power source, as compared to other solar collection technologies.[32] Ubiquitous Energy is a BIPV company that produces transparent solar windows. As of late 2020, the company's PV windows cost 20-30% more than traditional windows, with efficiencies reaching 9.8%. The modeled payback period for most buildings ranges from approximately 5-7 years. This range is considered to be desirable and this relatively quick payback period is critical if BIPV is going to attract attention from developers and homebuilders.[33]

Another significant barrier preventing BIPV adoption relates back to builders and their level of caution regarding new (unproven) materials. BIPV, and even more traditional solar PV technologies like solar panels, are "still in the process of gaining mainstream acceptance."[34] Builders are hesitant to use unfamiliar materials, as homes have to stand up to weather and wear longer than the 20 to 25-year warranties standard on many solar panels. For BIPV technologies, data is limited in terms of product durability and efficiency over time. Silicon has been used in the field for decades, but more innovative technologies like organic PV or perovskite are unproven.[35]

2.3 FACTORS DRIVING BIPV ADOPTION

A key question remains: What can be done—or what needs to be done—to drive BIPV adoption? A number of sources have addressed this topic.

Multifunctional BIPV solutions could be key for the increasing adoption of BIPV. If on-site energy generation is the primary goal for the builder or owner, solar panels bolted on to a rooftop are going to be less expensive than BIPV and this would be the most economical solution for many customers—at least for now. If BIPV can demonstrate other capabilities and features that extend beyond energy generation, this could help to justify the higher cost or result in a faster ROI.[36]

As BIPV solutions become more flexible and aesthetically pleasing, this may help with technology adoption. Aesthetics, while they are improving, were still cited as a notable hurdle for the BIPV market. The lack of visual appeal can be a problem, especially for high-end buildings or buildings where architectural style is a particular focus. Frameless BIPV modules can be uniform in color, but they can also vary in terms of form and structure. Monolithic integration is a related factor. Monolithically integrated BIPV roofing—where the distinction between the energy and roofing systems is blurred—is currently available on the market. Monolithic integration is also happening with BIPV glass. There are products that are self-tinting, self-cleaning, and even self-healing.[37]

The trend toward zero energy buildings may encourage BIPV adoption.[38] The New Buildings Institute has provided data summarizing the growth and trends from approximately 500 certified, verified, and emerging zero energy projects across the U.S. and Canada. The number of verified and emerging zero energy buildings and projects (in the U.S. and Canada) noticeably increased from 60 projects in 2012 to 482 projects in 2018, according to the New Buildings Institute.[39] As the trend continues toward zero energy buildings, there may be increased interest in BIPV solutions.

Favorable government policies could further promote BIPV and the adoption of this technology. Examples of government policies that could be impactful include the setting of ambitious targets for promoting zero energy buildings, developing tax incentives for buildings equipped with BIPV, and providing public funding for the research, development, demonstration, and installation of BIPV.[40]

There may be some misconceptions or a simple lack of understanding regarding BIPV technology. In October 2018, a paper titled "A Conceptual Framework for a Building Integrated Photovoltaics (BIPV) Educative-Communication Approach" was published in the journal *Sustainability*. This paper references findings from surveys on public educational barriers, stating that there is "poor public understanding of cost perceptions of BIPV and financial benefit understanding and a lack of sufficient knowledge by clients and the public in general."[41] Surveys also report a high negative perception of system price and the costs associated with BIPV options (and particularly those with a nice aesthetic). University courses focusing on BIPV are lacking. There seems to be a need to highlight the types of BIPV product options available, design strategies, technology performance, and cost issues need to be addressed. Other references and surveys report that there is a lack of technical knowledge, there is a limited number of certified BIPV contractors, and stakeholders have insufficient knowledge regarding BIPV system advantages, risk, and complexity.[42]

A report from the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and Becquerel Institute, titled *Building Integrated Photovoltaics: A Practical Handbook for Solar Buildings' Stakeholders*, was published in 2020. While this report examines the BIPV landscape from a European perspective, much of the information translates to the U.S. market, as well. As noted earlier, factors supporting the use of BIPV technologies include a decrease in manufacturing costs for such solutions, increasing product performance, growing regulatory and social pressure to implement renewable energy technologies and reduce the environmental footprint of buildings, and the fact that current BIPV products can be highly customized and introduced to the construction sector as conventional elements.[43]

A lack of standardization has been cited as a hurdle to BIPV adoption. It is believed that standardization will ultimately be needed to help reduce the complexity (and also the costs) of BIPV installations.[44] In Europe, a number of manufacturers have complained about the lack of long-term guarantees of available BIPV solutions and that it can be impossible to certify or mark BIPV products according to one clear approach or standard. National building codes can impose overly restrictive constraints for BIPV (such as for fire safety) and these building codes can vary by country (and perhaps also state, city, etc.). This can prevent BIPV manufacturers and installers from rapidly expanding their customer base and increasing production capacities—which if done correctly, would reduce costs through economies of scale.[45] In addition, BIPV is still working to gain widespread acceptance, from an aesthetic standpoint.

The optimization of the BIPV process is a factor that would increase adoption. Flexible product concepts, mounting systems, or pre-assembled products that require less time and expertise for installation are required by stakeholders. According to the report from SUPSI and Becquerel Institute, "today, the installation of a BIPV system often frightens façade makers, electrical installers, and in general the stakeholders of the traditional building process.”[46] Many architects and installers lack experience and knowledge regarding BIPV, and they also lack coordination among key partners—including building owners, material suppliers, and installers. These issues might be addressed by creating a digital process or BIPV consulting services, which would make the process of integrating BIPV less intimidating. Handbooks for certifications, installation details and tutorials could simplify planning and on-site installation. Getting BIPV suppliers involved early in the development process is seen as being key for simplifying the entire process. Digitization and improved tools—such as building information management, or BIM, solutions—may be helpful in optimizing and “overcoming the fragmentation of the BIPV project development process.”[47]

Other noteworthy obstacles to BIPV adoption include the higher upfront cost of many BIPV technologies compared to conventional solutions, conservatism, resistance to change, and “misperception of incumbent actors of the construction value chain (from product manufacturers to architects and general construction companies).”[48] The key stakeholders (builders, architects, etc.) have little interest in BIPV currently, primarily because volumes are limited and there are no legally binding constraints to develop the segment.[49]

In 2019, The RICS Research Trust published a report titled *Cost Reduction and Deployment of Prefabricated Building Integrated Photovoltaics*. The report identifies a number of hurdles to BIPV adoption and highlights efforts to address those hurdles. Aesthetics have been discussed as a barrier to BIPV adoption. In order to accelerate BIPV uptake, the difference between BIPV and conventional building envelope materials should be minimized as much as possible (in terms of both architectural and construction aspects). As a result of this potential barrier, recent R&D has focused on the development of colored BIPV and modules of various sizes—which would greatly help with aesthetics. Anti-reflection color coating is one method used to add color. Some thin-film and organic PV modules have colored or semi-transparent layers to increase light intake. More R&D may be helpful in terms of developing cost-effective BIPV materials that offer design flexibility and production flexibility—along with energy efficiency and improved building performance.[50]

In addition to colored BIPV and more attractive materials, the industry may also benefit from advances in manufacturing and installation. BIPV modules can be quite heavy and their weight needs to be considered when one is designing a BIPV building. If BIPV is being installed as a retrofit or refurbishment, the existing structure may not even be able to support the additional weight of BIPV modules. Thin-film BIPV cells can be a better alternative, but they are often less cost-effective in comparison to modules, in terms of the payback period.[51] According to the report from The RICS Research Trust, increasing knowledge awareness, support for BIPV business models, BIPV product and process standardization, BIM-enabled BIPV design assessment and optimization, and quality assurance in procurement are noted as being key deployment drivers for BIPV technology.[52]

2.4 EXPLORING KEY CHALLENGES: COST AND INSTALLATION

This section discusses two key challenges that seem to be preventing the more widespread adoption of BIPV—cost and complexity of installation.

2.4.1 COST

A benefit and challenge of BIPV, as opposed to solar PV, is that for fully integrated architectural applications one size does not fit all. However, today glass is a customizable architectural component, and any solar-based substitutes must conform or will not be considered for integration into the building envelope. Qualities considered include varying transparency levels, and somewhat arbitrary sizes, which presents a significant technical challenge for BIPV because of the cost implications associated with designing, manufacturing and certifying a range of sizes.[53]

Furthermore, from a technical and aesthetic standpoint, the uniform appearance of thin-film panels over large areas provides an advantage over wafer-based Si. Presently, Si dominates the roof BIPV market compared to thin-films with a 90/10 market split, thin-films dominate façades with a 56/44 split. While the architectural glass industry is already well-versed in 'soft' coatings such as sputtered low-E coatings, protected inside dual panes the idea of replacing these with thin-film cell 'coatings' seems a logical extension. However, the lack of precision in manufacturing customized integrated glass units (IGUs) poses a challenge and requires technical innovations that would utilize an additional glass lite to fully seal the PV against moisture. Options to improve functionality and reduce cost also include increasing moisture resistance in thin-films, which could minimize these costs and relax design constraints. Researchers note that another large opportunity is to utilize commoditized solar panels in place of building components. This could be a significant improvement if architects adapted to a standard form factor, which sometimes happens with cladding systems, and substantial costs could be avoided. "*A vertical solar system costing $2– 3 watt−1 (installed) at 18% efficiency, equates to $3.90–5.85 m−2. Most Aluminum Composite Material (ACM) exterior wall cladding systems common to commercial construction, have installed costs of ~$2.75–4.65 m−2.*"[54]

This cross section of cost and customization is illustrated in the figure below from the Fraunhofer-Institute for Solar Energy Systems ISE.

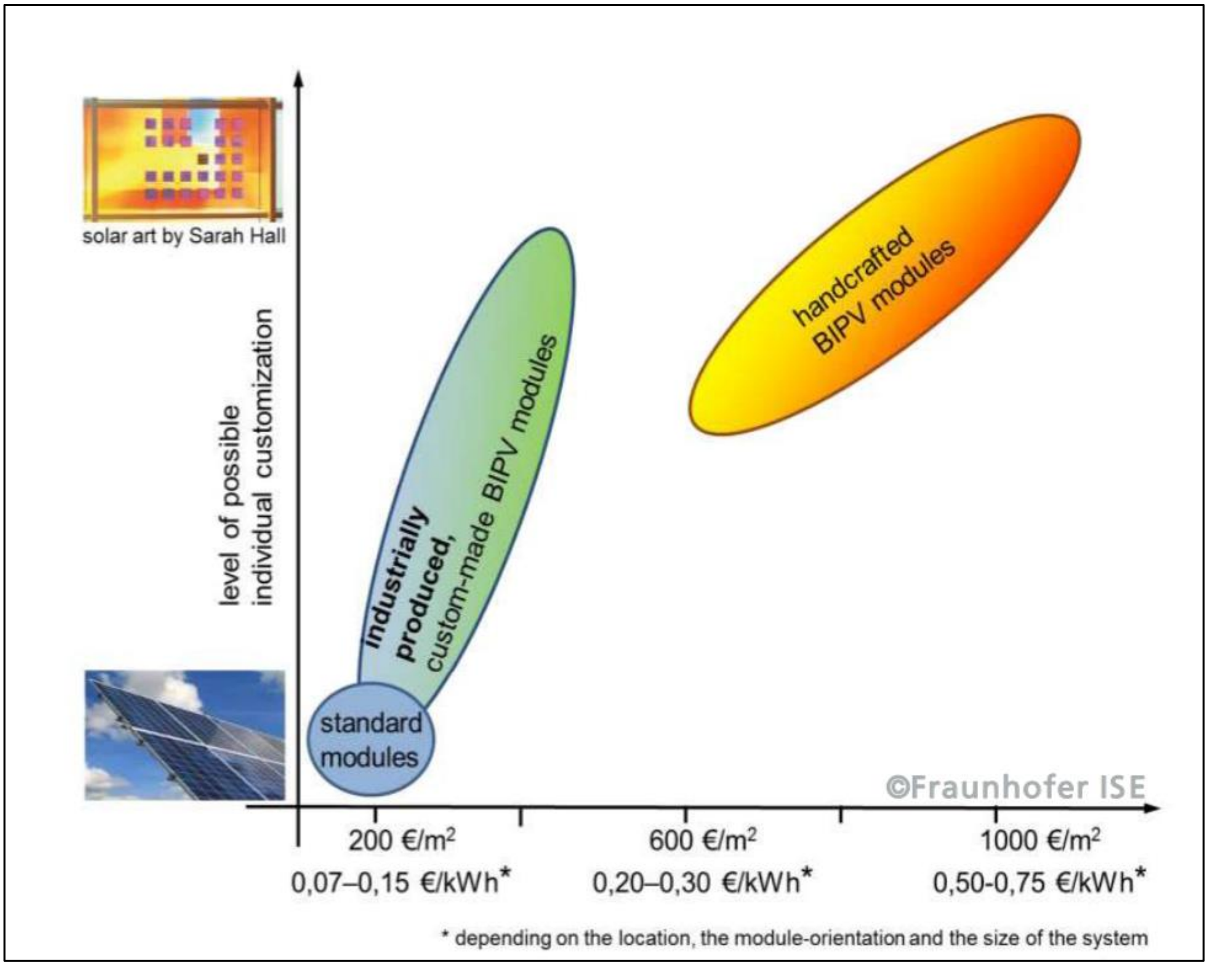


Figure 1: BIPV Cost & Level of Customization[55]

A report from RICS[56] goes on to discuss cost reduction and deployment of prefabricated building integrated photovoltaics, and specifically covers soft costs. As explored by RICS, BIPV soft costs include all other costs except the system hardware, these include the costs spent during the entire BIPV lifecycle for getting the systems up and running, from the design stage to operational stage until the end of its lifecycle.

Table 1: BIPV Soft Costs in Different Countries[57]

Country	Soft Cost	System specifications	Cost (US$)	Year
Germany	Administrative costs (law-related)	5 KW BAPV system	0.01/W	**2017**
	Administrative costs (PII)	5 KW BAPV system	0.01/W	**2017**
	Customer acquisition cost	5 KW BAPV system	0.04/W	**2017**
	Marketing and advertising cost	5 KW BAPV system	0.02/W	**2017**
	Packing	ASI Glass modules (1205 X 1028 X 27 mm) 50 Wp,53 kg	9.25/kg	**2009**
	Freight (15% of product cost)	ASI Glass modules (1205 X 1028 X 27 mm) 50 Wp,53 kg	71.26/kg	**2009**

	Overhead & profit (installer firm)	5 KW BAPV system	0.23/W	**2017**
	Grid connection and commissioning	5 KW BAPV system	0.02/W	**2017**
	PII costs	5 KW BAPV system	0.06/W	**2014**
Italy	Designing and project management	11KW Polycrystalline BIPV roofing system	0.32/W	**2016**
	Transport	11.52 KW system with Mono-crystalline BIPV roofing	2.20/W	**2012**
	Installation cost (Total)	11KW Polycrystalline BIPV roofing system	0.64/W	**2016**
	Installation cost (Electrical BOS)	11.52 KW system with Mono-crystalline BIPV roofing	1.26/W	**2012**
	Installation cost (Structural BOS)	11.52 KW system with Mono-crystalline BIPV roofing	1.17/W	**2012**
	Inverter replacement	11.52 KW system with Mono-crystalline BIPV roofing	0.95/W	**2012**
Greece	Design, engineering and installation costs	2.25 KW Mono-crystalline BIPV roofing system	2.44/W	**2003**
	Feasibility study, development and miscellaneous	9.87 KW BAPV system	0.12/W	**2017**
	Transport	2.25 KW Mono-crystalline BIPV roofing system	0.48/W	**2003**
	Installation cost (Electrical BOS)	2.25 KW Mono-crystalline BIPV roofing system	2.76/W	**2003**
	Installation cost (Structural BOS)	2.25 KW Mono-crystalline BIPV roofing system	2.82/W	**2003**
	Monitoring	2.25 KW Mono-crystalline BIPV roofing system	0.48/W	**2003**
	Inverter replacement	2.25 KW Mono-crystalline BIPV roofing system	1.98/W	**2003**
US	Customer acquisition	5.6 KW residential BAPV system	0.31/W	**2016**
	PII costs	**5 KW residential BAPV system**	**0.24/W**	2014

Conversely, BIPV hardware mainly consists of PV modules, inverters, storage devices, fixing accessories and cabling. Hardware broadly falls under two main categories: (1) BIPV modules and (2) Balance of System (BOS) (inverters, storage devices, fixing accessories, cabling and other).[58]

Cost reduction is typically dependent upon several interrelated factors. The figure below illustrates these relationships. The connections between hardware cost reduction potentials are shown in blue arrows and soft cost reduction potentials in red arrows. The connections between hardware and soft cost reduction potentials are shown in white arrows.[59]

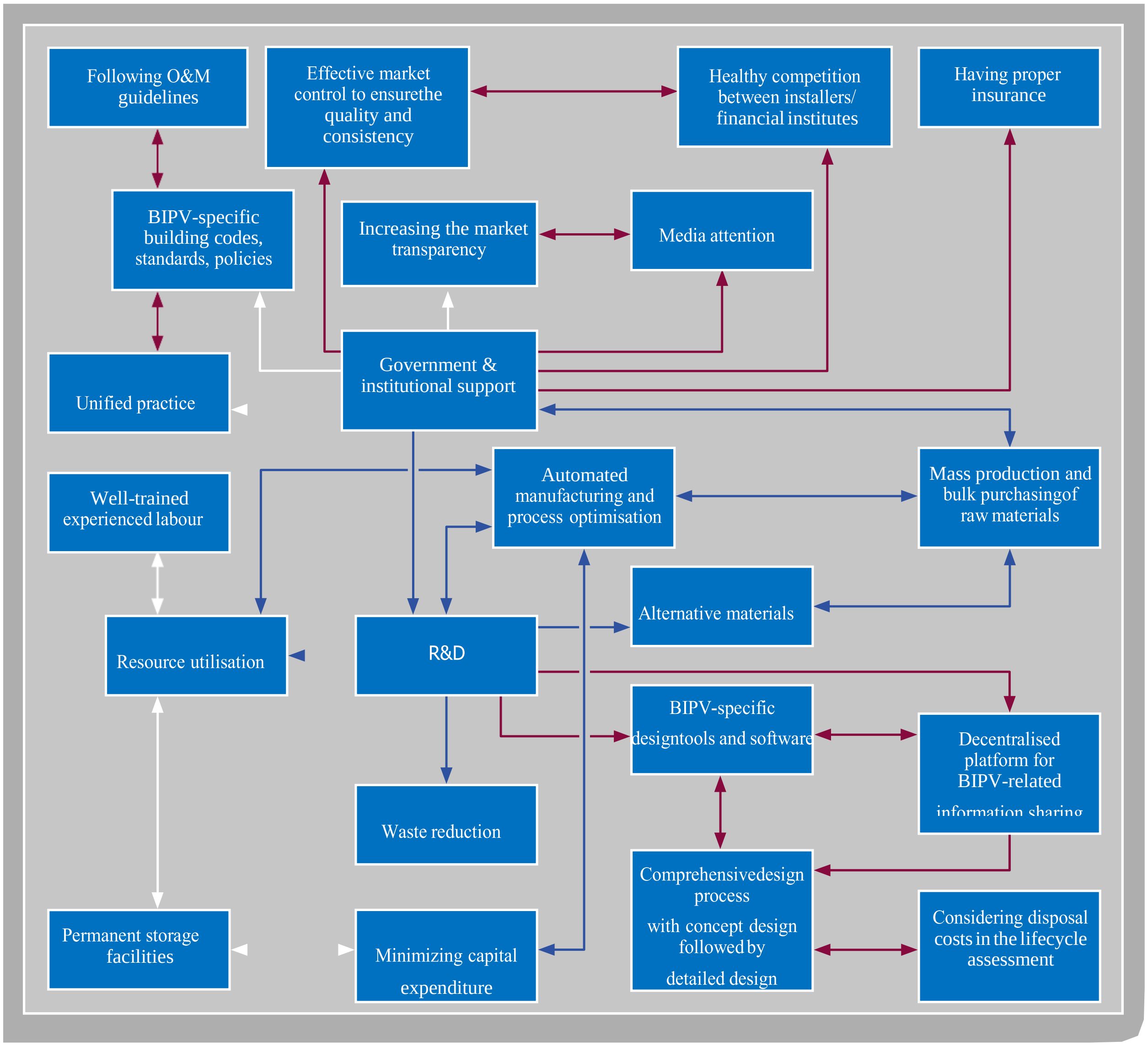


Figure 2: Relationship Map of BIPV Cost Reduction Potentials[60]

2.4.2 INSTALLATION

The following provides a discussion of the BIPV installation process and the challenges associated with this task. Factors impacting BIPV installation and construction include skilled labour, construction supervision, specialized consultation, health and safety, and project contingencies such as delays and training. One installation challenge for BIPV is that it consumes more time for installation due to the high number of modules but, since these modules are relatively small, they are easier to move and handle than BAPV modules. BIPV modules also do not require the installation of mounting systems prior to the installation of modules, which are needed for BAPV, and therefore makes the BAPV installation process longer - yet BIPV requires a complex and time-consuming electrical wiring process. According to the cost comparison of the NREL report from 2011, the total installation cost of a c-Si BIPV roof system is lower than the total installation cost of a similar BAPV roof system.[61]

As noted throughout the report, aesthetics and environment have a significant impact on new BIPV installations. For example, BIPV products should imitate the original appearance of traditional construction materials while performing their energy-generating functions.[62] Furthermore, the specific building typology and building envelope for the BIPV installation are important factors influencing installations. The figure below provides a flowchart of main barriers for BIPV implementation.[63]

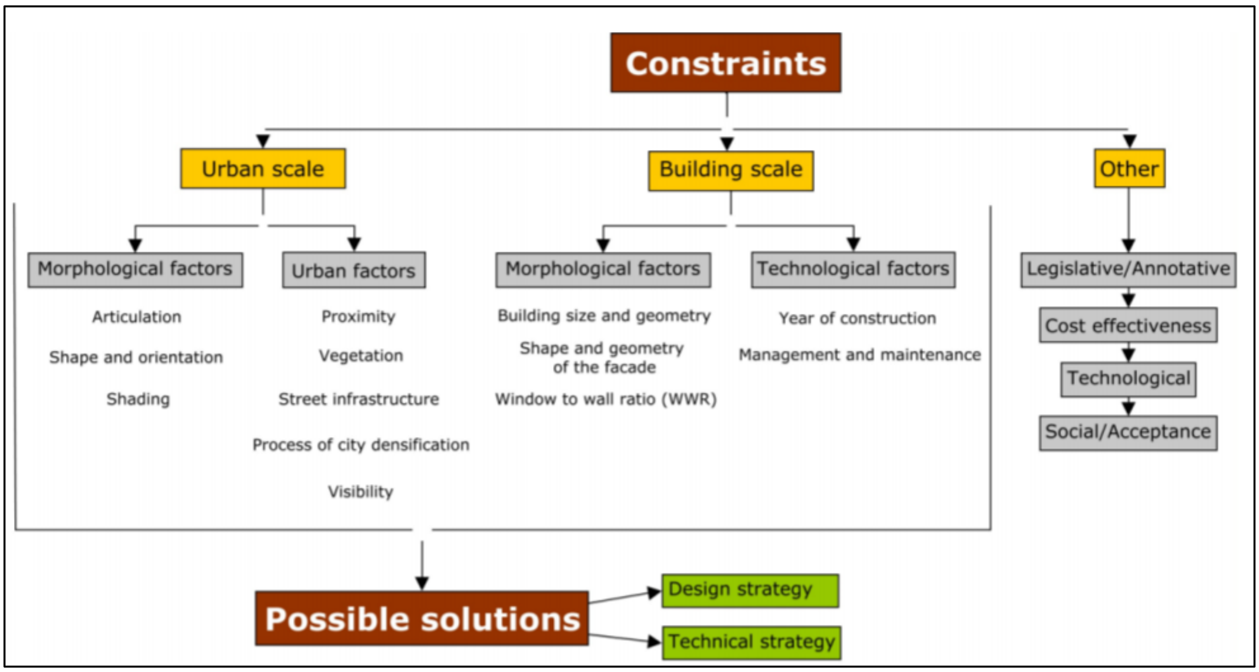


Figure 3: Flowchart of Main Barriers for BIPV Implementation[64]

Additional factors impacting installation include accurate electrical wiring, the use of appropriate PV technology or technical devices (power optimizers, micro inverters, by-pass diodes, dummies) that can moderate or eliminate some problems such as shading, non-optimal exposure, etc. Implementing an accurate BIPV design approach during architectural concept and building skin engineering is said to help avoid and prevent some of the critical aspects affecting PV energy behavior. Despite these technical challenges in design and installation, the biggest barriers to BIPV adoption are not technical.[65]

In terms of installation system options, it appears that two main systems are used: Mullion-transom façades and Structural sealant glazing (SSG). “Mullion-transom constructions consists of vertical mullions and horizontal transoms. The mullions transfer the main loads and the transoms act as horizontal bracing. The solar modules are set in this framework structure as fill elements. Clamping rails are fitted from the outside as linear fixings for the modules. With structural sealant glazing façades, the solar modules are fixed in place on a metal frame by means of circumferential load-transferring bonds."[66] The installation system is most frequently impacted by regulations – different countries require different types of installations.

2.5 SUMMARY

BIPV systems are planned during the architectural design stage and the PV technologies (which may include PV rooftops, facades, and glazing applications such as windows and skylights) are added during the initial construction of the home or building. Closely related to BIPV is BAPV—or building-added photovoltaics. BAPV is planned and built during a retrofit. Aesthetics and energy savings are some of the leading advantages of BIPV over traditional PV products and other building materials, but challenges of cost, acceptance, and installation are hindering growth and adoption. It appears that multifunctional BIPV solutions could be key for the increasing adoption of BIPV. If on-site energy generation is the primary goal for the builder or owner, solar panels bolted on to a rooftop are going to be less expensive than BIPV and this would be the most economical solution for many customers—at least for now. If BIPV can demonstrate other capabilities and features that extend beyond energy generation, this could help to justify the higher cost or result in a faster ROI. Favorable government policies could further promote BIPV and the adoption of this technology while also helping to overcome gaps in customer knowledge about the products.

3.0 Market Size & Regional Policies

3.0 MARKET SIZE & REGIONAL POLICIES

This section discusses the global BIPV market size and growth, as well as the regional segmentation, trends, policies, and incentives relative to the European, Asian, and U.S. markets. This market information on revenue and capacity provides some insight as to how these regions are successfully pushing BIPV adoption. The market size and growth data provided is also segmented by application area, indicating which specific BIPV elements (i.e., roofing, glazing, facades, architectural shading) are most often used in the various regions, as well as the segments poised for growth in the near-term.

When reviewing market sizing information from multiple sources it is important to take the methodology and scope of each source into consideration. Within the context of this report, market sizing data has been derived from a variety of sources, including BCC Research. The base year for analysis and projection by BCC Research is 2019, and market projections were developed for 2020 to 2025. These projections are based on a combination of the primary research conducted by BCC Research, as well as their understanding of key market drivers and their impact from a historical and analytical perspective. Revenue forecasts for this period are segmented based on technology, application, end user, and geographic region. BCC Research notes the limitations of their study, as listed below:

- “The scope of the report includes the global market of commercially deployed BIPV projects.
- The projects that are in the design phase or the pre-development phase have not been considered in the calculation of the overall market size.
- The market size includes the market of both hardware as well as the service part.
- The after-sales services market such as software upgrade or hardware maintenance has not been considered in the report.
- The report includes both new constructions as well as renovation projects for the calculation of overall market size.
- Utility-scale power grid projects have not been considered in the report scope.”[67]

Additional sources explore the market from a capacity standpoint and each source takes different factors into consideration when making its projections. For example, these sources may differ by regional segmentation, type, or location of BIPV (window, façade, roof), base year, and sources used.[68]

3.1 GLOBAL BIPV MARKET SIZE AND GROWTH

According to BCC Research, the global market for BIPV is segmented by application, with application segments including roofing (roofing shingles, roofing tiles, standing seam metal roofing, and single-ply membrane roofing), facades, glazing, and architectural shading. The BIPV market is also segmented by end user, with residential, commercial, and industrial being the key segments. Factors driving the market include regulations and incentive plans proposed and/or enacted by governments around the world, a surge in the demand of BIPV systems for retrofit projects, the development of new technologies which are helping to improve product efficiency and return on investment (RoI), and an increasing demand for near zero-energy buildings largely as a result of growing concern for the environment. Restraints that are specific to the BIPV market include the lack of standards for BIPV across the industry, the short lifespan of the various products and services, and cost (BIPV materials are often not cost-competitive with conventional building materials).[69]

Application segments of the BIPV market include roofing (which is further broken down to encompass roofing shingles, roofing tiles, standing seam metal roofing, and single-ply membrane roofing), facades (this includes building cladding and green parking structures), glazing (windows, curtain walls, skylights, and breezeways), and architectural shading.

Table 2: Global Market for BIPV, by Application (USD Million)[70]

Application	2019	2020	2021	2023	2025	CAGR (2020-2025)
Standing seam metal roofing	955.4	951.6	1,098.3	1,582.8	2,438.4	20.7%
Roofing tiles	396.9	420.4	516.2	844.2	1,482.1	28.7%
Single-ply membrane roofing	305.5	330.3	413.5	700.1	1,267.7	30.9%
Roofing shingles	331.8	350.7	429.8	700.5	1,225.9	28.4%
Glazing	788.6	806.2	956.5	1,463.6	2,411.3	24.5%
Facades	702.4	695.2	797.9	1,139.8	1,746.8	20.2%
Architectural shading	314.7	306.6	345.9	475.6	696.9	17.8%
Total	3,795.3	3,861.0	4,558.1	6,906.6	11,269.1	23.9%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

BIPV roofing represents the largest near- and mid-term market segment. Roofing includes roofing shingles, roofing tiles, standing seam metal roofing, and single-ply membrane roofing. Green building trends and guidelines, along with the Net Zero Energy Building (NZEB) mandate in China, Europe, and similar efforts in parts of the U.S. are driving the PV roofing market. With respect to standing seam metal roofing—this type of roofing is more prominent in the southeastern United States (as well as in Scandinavian countries). The southeastern U.S. may be a key region, as this region both embraces this roofing style and many states in this region are supporting requirements and incentives to support the development of solar resources "in the absence of access to other significant renewable energy resources (such as biomass, biogas and onshore and offshore wind)."[71]

The façade market may be unique in the sense that this might be the first sector where the BIPV module is of equal cost to the component it is replacing. Exteriors such as marble and sandstone cost approximately $500 per square meter, which is a similar price point to that of high-capacity PV modules. The application of PV modules as facades has been seen in building structures where materials such as marble, steel, and metalized panels would ordinarily be used. Municipal green building codes (such as those in New York City) have encouraged builders and architects to design skyscrapers and high-rise apartment buildings that have PV modules integrated into the southern-facing upper floors. Facades have also been used on buildings in corporate parks and campuses.[72]

Building cladding is used to seal the horizontal faces of a building, preventing the penetration of heat, humidity, precipitation, and vermin. Cladding serves as a barrier that protects the interior of a building from the environment and elements, it provides some insulation for the building, and is a primary component when it comes to building design aesthetics. The market prospect for BIPV building cladding products has slightly higher potential in commercial and industrial buildings.[73]

Green parking structures (parking garages) may be an interesting application area for BIPV. BIPV options for parking structures include glazing, shading and canopies on open-top floors. Parking structures are generally unappealing, in terms of appearance, and the addition of BIPV may enhance the appearance of the structure—in addition to creating an energy-positive and captive green power plant. Parking garages and ramps represent a relatively new area for BIPV components. The structures are comprised of multiple stories of rectangular openings with little to no embellishments on the exterior wall finish. The top floor of a parking garage is typically a large, open, unshaded area that could offer potential for a solar carport, or a solar canopy that could go over the entire surface of the upper floor. These types of "solar carports" or canopies have also been built for ground-level parking lots. This trend toward green parking structures is being seen on an international scope. The Green Parking Council (associated with the Green Building Council) has developed a certification process for LEED credits for parking structures. Internationally—particularly in Asia—automated parking garages are an increasing trend. Cars are driven into a small room in the structure, a ticket is given to the driver by an automated teller, and then the car is automatically lifted and moved to a parking spot. These multi-story automated parking garages are typically encased in cladding.[74]

BIPV glazing is already priced competitively, when compared with higher-end architectural glass, so pricing is less of a restraint with PV windows and BIPV glazing applications. BIPV glazing can also accumulate LEED and Building Research Establishment Environmental Assessment Method (BREEAM) points, which enhance the building value.[75]

Architectural shading is a market niche with some potential, as the use of awnings and architectural shading elements is common. Architectural shading can be added after a building is up and it would still be considered "BIPV." Shading provides function, in addition to power generation. However, for this segment to grow, the PV must generate more cost savings within a 7-year timeframe than it costs to add the BIPV shading element.[76]

3.1.1 BIPV MARKET SIZE (MW)

While market sizing figures tend to focus on quantifying the market in terms of revenue, another way to look at the global BIPV market in by capacity or megawatts (MW). The annual global BIPV installation was predicted to be 1152.3 MWp in 2019, with a Compound Annual Growth Rate (CAGR) of 18.7%, compared with the 343.1 MWp in 2012. Tabakovic et al. reported[77] on the status and outlook of global BIPV installations from 2014 to 2020 by region, as illustrated in the table below. This table provides historical data and projections but may be useful when assessing the total addressable market (TAM). Per this report, "the global installation was estimated to be 2.3 GW in 2015, while the market was only 1.5 GW in 2014, thus, the increasing rate almost reaches 50%."[78] From a regional perspective, Europe, Asia, and the U.S. played a dominant role in the global BIPV market. Europe accounted for approximately 41.7% of the BIPV market in 2015. The average global CAGR of 39% during 2014–2020 projects that the annual global BIPV installation in 2020 was anticipated to be 11 GW.[79] For reference and future projections, BCC Research reports that the BIPV market is expected to grow at a CAGR of 23.9% to from 2019-2025.[80]

Table 3: The Global Building-Integrated Photovoltaic (BIPV) Market Development and Forecast from 2014 to 2020 (MW)[81]

Region/Country	2014	2015	2016	2017	2018	2019	2020	CAGR (%)
Asia/Pacific	300	492	772	1159	1672	2329	3.134	47.8
Europe	650	967	1441	2103	2929	3807	4838	39.7
USA	319	476	675	917	1200	1491	1766	33.0
Canada	42	61	86	119	157	190	228	32.6
Japan	143	201	268	349	434	520	612	27.5
Rest of world	81	125	184	263	355	451	561	37.9
Total (GW)	1.5	2.3	3.4	4.9	6.7	8.8	11.1	

Note: This information is originally from a Global Industry Analysts report published in 2015.

Additionally, the International Energy Agency reported the electricity potential of BIPV for some of its member countries, including the U.S. This analysis was completed through the evaluation of the available roof and façade areas of residential, agriculture, industrial, commercial areas, and those of other buildings – the corresponding electricity generation potentials and the potential-consumption ratios of the roof and façade areas in these countries were predicted and listed in the table below.[82]

Table 4: The Potential Electricity Generation Capacity of Building-Integrated Photovoltaics (BIPVs) for the Selected Countries of International Energy Agency (IEA)[83]

Country	Potential Area of Roofs (km2)	Potential Area of Façades (km2)	Potential of Roofs (TWh/ year)	Potential of Façades (TWh/ year)	Total Potential (TWh/ year)	Actual Consumption (TWh)	Potential -Demand Ratio (%)
Australia	422.5	158.34	68.176	15.881	84.057	182.24	46.1
Austria	139.62	52.36	15.197	3.528	18.725	53.93	34.7
Canada	963.54	361.33	118.708	33.054	151.762	495.31	30.6
Denmark	87.98	32.99	8.710	2.155	10.865	34.43	31.6
Finland	127.31	32.99	11.763	3.063	14.827	76.51	19.4
Germany	1295.92	485.97	128.296	31.745	160.040	531.64	30.1
Italy	763.53	286.32	103.077	23.827	126.904	282.01	45.0
Japan	966.38	362.39	117.416	29.456	146.872	1012.94	14.5
Netherlands	259.36	97.26	25.677	6.210	31.887	99.06	32.2
Spain	448.82	168.31	70.689	15.784	86.473	180.17	48.0
Sweden	218.77	82.04	21.177	5.515	26.692	137.12	19.5
Switzerland	138.22	51.83	15.044	3.367	18.410	53.17	34.6
United Kingdom	914.67	343.00	83.235	22.160	105.395	343.58	30.7
United States	***10,096.26***	***3876.10***	***1662.346***	***418.312***	***2080.661***	***3602.63***	***57.8***

Note: This information is originally from an IEA report published in 2002 (Report IEA-PVPS17-4:2002).

The available areas of these countries vary quite a bit, which is primarily attributed to their land areas, economic levels, architectural spaces, and shapes.[84] Additionally, given that there are many different figures and methods for approaching the market size, the figure below provides global projections of annual BIPV capacity from several different groups.

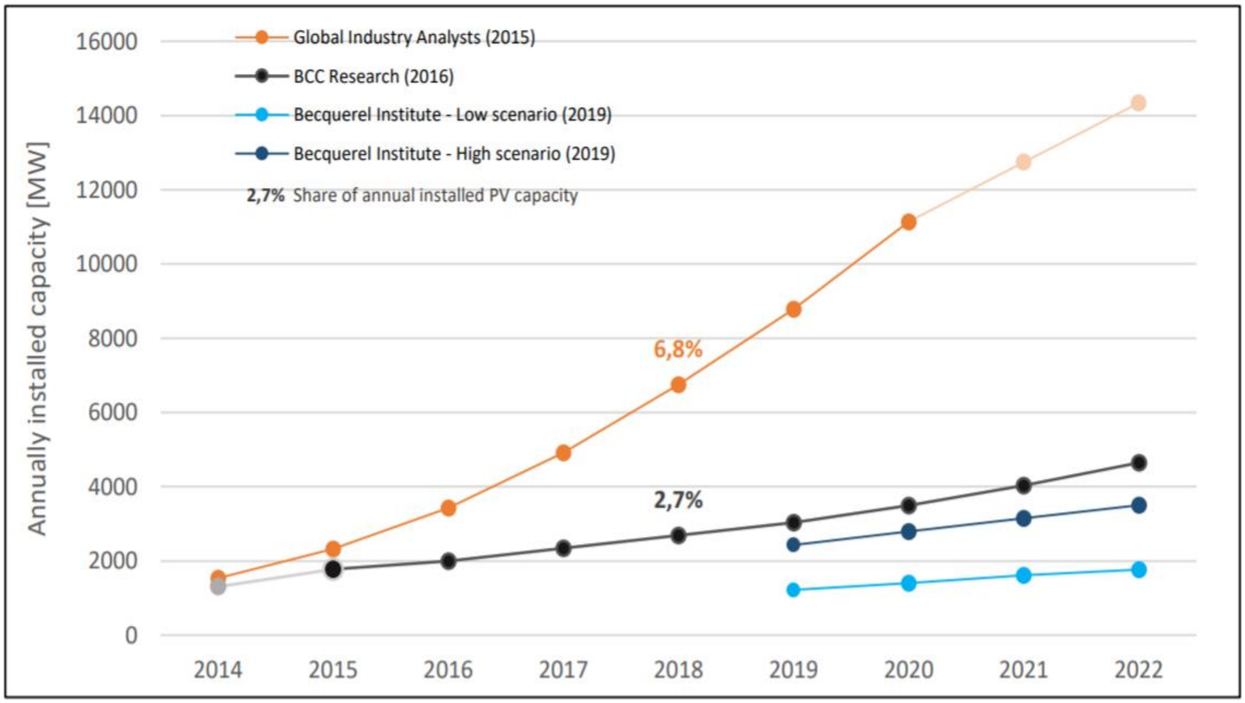


Figure 4: Projections of the Annual BIPV Capacity Installed Worldwide, from Different Organizations[85]

Research out of the California Institute of Technology assesses the case for market deployment of BIPV windows, specifically intended for commercial U.S. high-rise buildings. The researchers found that BIPV installations currently occupy less than 0.001% of the overall solar market share in the U.S. and that BIPV market forces are complicated by a misalignment of incentives between the end users of BIPV windows and the key decision makers for building projects that could incorporate this technology – this finding was based on over 150 interviews and secondary research.[86] The following two figures culled from this research illustrate some of these key points:

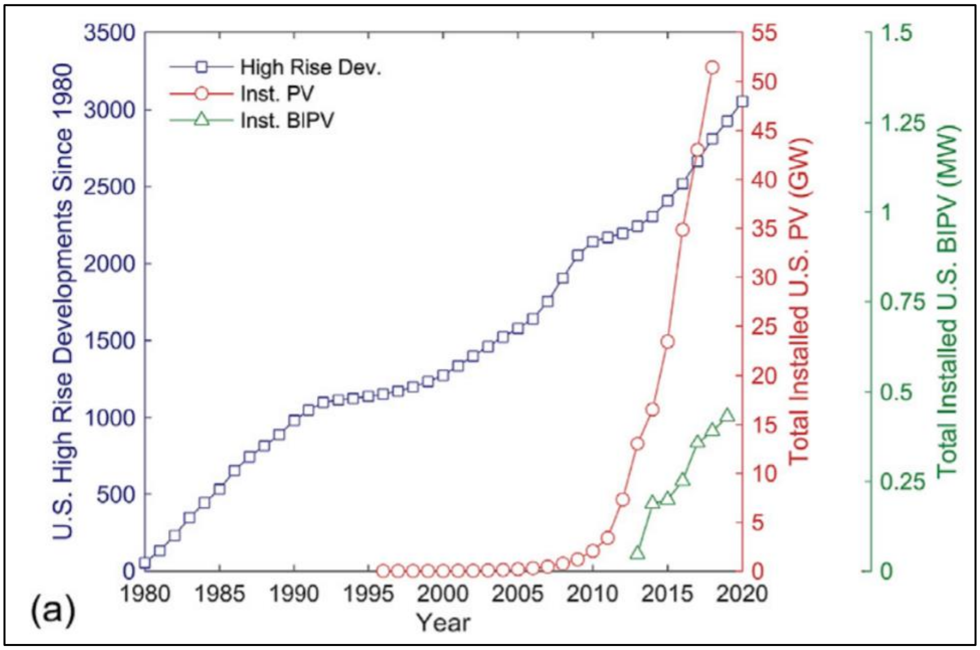


Figure 5: A Comparison of the Number of U.S. High-Rise Developments Since 1980 (left y-axis, blue) Against the Total Installed U.S. PV Capacity (right y-axis, red) in GW and the Total Installed U.S. BIPV Capacity (far right y-axis, green) in MW[87]

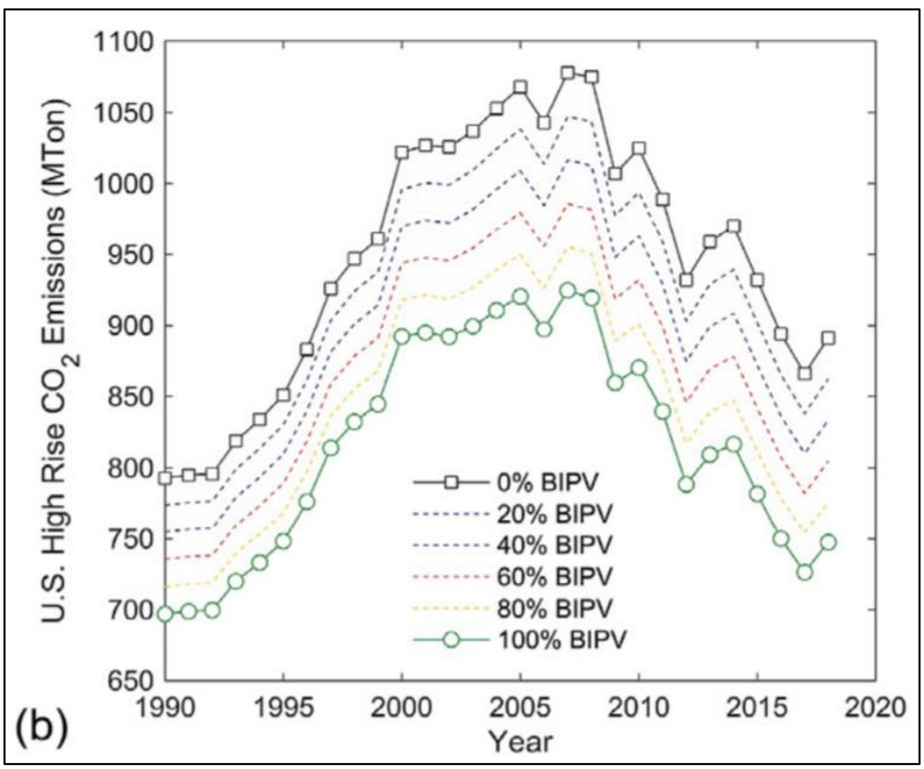


Figure 6: An Estimate for the Amount of CO_2 Emissions in Megatons (MTon) Resulting from U.S. High Rise Buildings with Respect to Varying Total Amount of BIPV Integration[88]

As introduced above, the amount of installed BIPV technology has not experienced the same growth as its utility PV counterpart, despite decades of device research and product development, and research into how to further integrate BIPV windows into the commercial buildings market remains an active area of study in both academia and industry. One possible explanation is that BIPV window modules have not yet achieved sufficiently high PCE and annualized energy production in order to meaningfully offset building electrical loads. Another possible explanation is that the customers' needs and associated value propositions for the BIPV market are significantly different from those of the utility-scale PV market.[89]

Another way to look at the market is segmented by type of system and type of surface/structure. The figure below illustrates the energy density factor in BIPV, which is an important factor in the choice of photovoltaic technologies used to optimize the available surfaces and the subsequent production of electricity.[90]

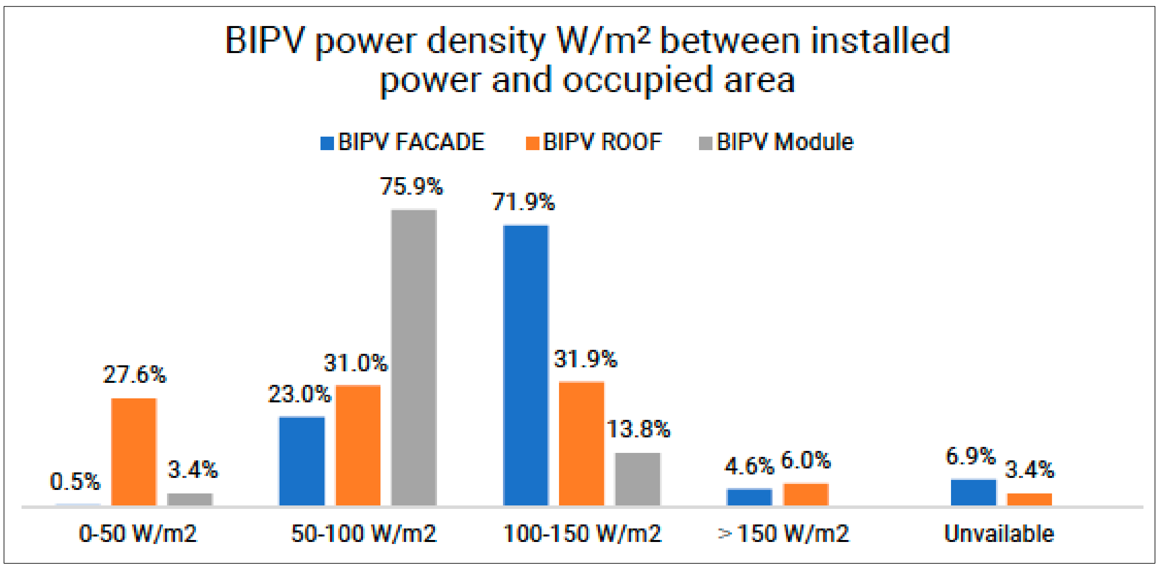
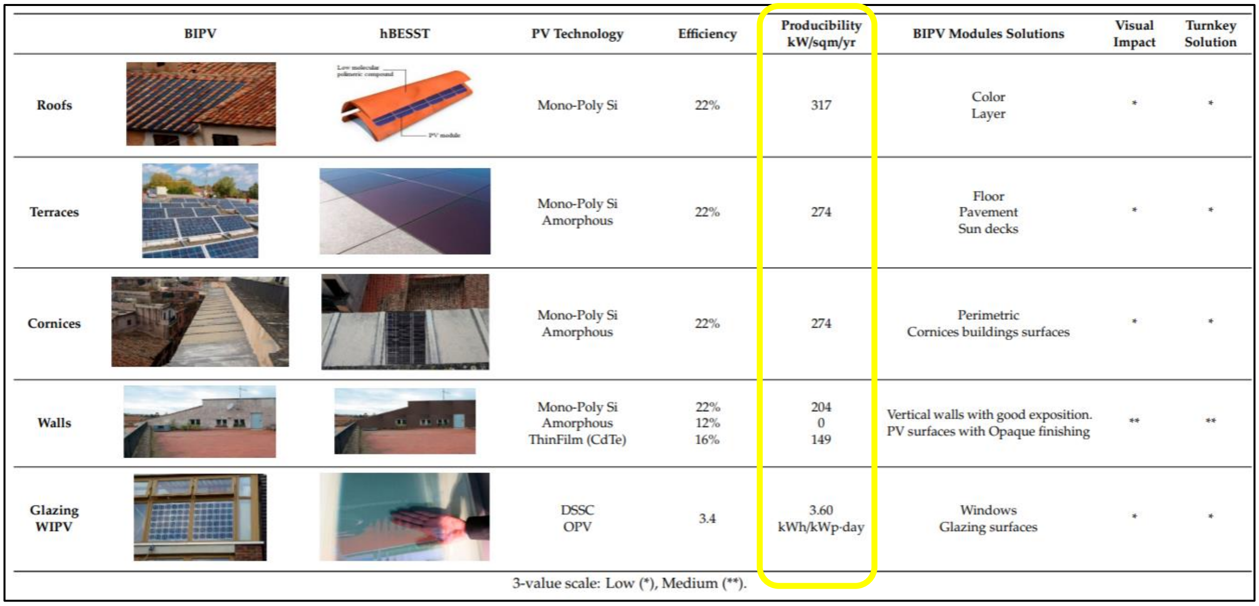


Figure 7: Power Density (W/m2) BIPV Modules by the Installation (2020)[91]

When looking at the market from the perspective of types of system/surface (roof, façade, etc.), different technologies yield different results. As noted throughout the report, historical buildings and materials are an important segment of this market. The table below shows how some Building Heritage Energy Solar Solutions Technology (hBESST) solutions on building envelope components on historical buildings can be developed with technologies already available on the market. While the table does focus on hBESST or THBs, these same components and technologies may be applied to other types of structures.[92]



	BIPV	hBESST	PV Technology	Efficiency	Producibility kW/sqm/yr	BIPV Modules Solutions	Visual Impact	Turnkey Solution
Roofs			Mono-Poly Si	22%	317	Color Layer	*	*
Terraces			Mono-Poly Si Amorphous	22%	274	Floor Pavement Sun decks	*	*
Cornices			Mono-Poly Si Amorphous	22%	274	Perimetric Cornices buildings surfaces	*	*
Walls			Mono-Poly Si Amorphous ThinFilm (CdTe)	22% 12% 16%	204 0 149	Vertical walls with good exposition. PV surfaces with Opaque finishing	**	**
Glazing WIPV			DSSC OPV	3.4	3.60 kWh/kWp-day	Windows Glazing surfaces	*	*

3-value scale: Low (*), Medium (**).

Figure 8: Comparison Between Traditional BIPV and BHEST Solutions on Historical Building Envelopes and Technological and Visual Impact Parameters (2020)[93]

3.1.2 MARKET SEGMENTATION BY BUILDING STOCK CLASSES

The commercial sector is expected to continue to make up the majority of the BIPV opportunity in the future as it does today, but residential BIPV is forecast to grow at a much faster rate and is expected to account for 15% of the worldwide BIPV market by 2023 generating $872 million in revenues.[94]

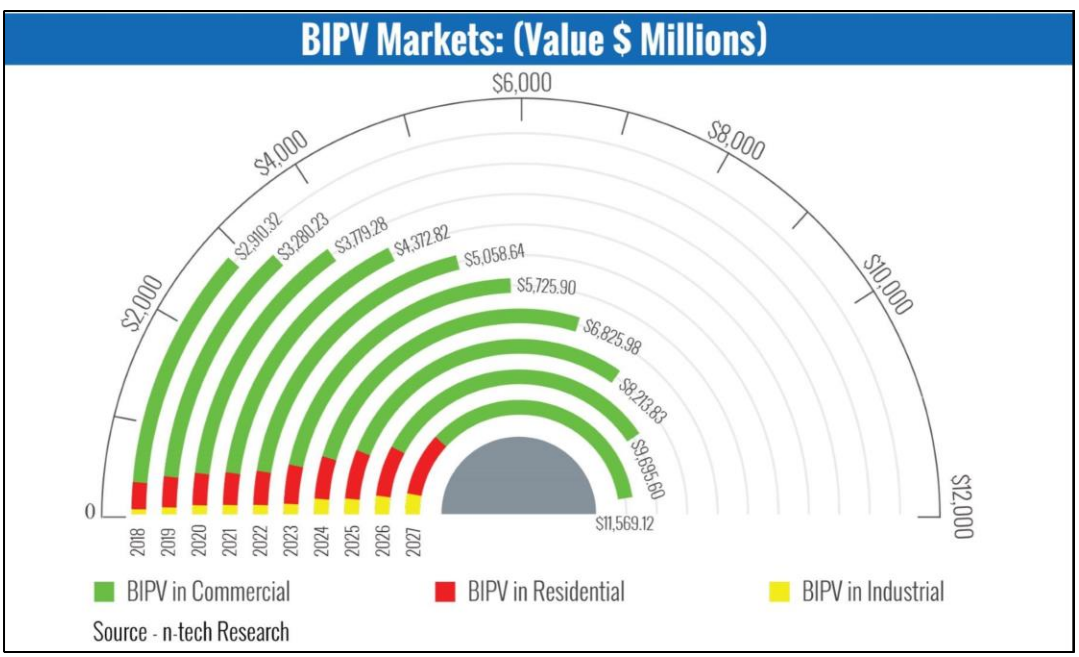


Figure 9: BIPV Markets (Value $ Millions, 2018)[95]

BCC Research explores this from a global and regional perspective, although it should be noted that regionally, the Americas include North, Central, and South America. As explained by BCC Research, each of the meta-categories (residential, commercial, and industrial) has its own set of predefined specificities, in terms of technical and economical characteristics.

Table 5: Global Market for BIPV, by End User (USD Million)[96]

End User	2019	2020	2021	2023	2025	CAGR% 2020-2025
Industrial	1,523.0	1,532.7	1,789.2	2,650.2	4,225.8	22.5
Commercial	1,231.6	1,259.0	1,492.4	2,278.9	3,745.5	24.4
Residential	1,040.7	1,069.3	1,276.5	1,977.5	3,297.8	25.3
Total	3,795.3	3,861.0	4,558.1	6,906.6	11,269.1	23.9

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Table 6: Global Market for BIPV in Residential Buildings, by Region (USD Million)[97]

Region	2019	2020	2021	2023	2025	CAGR% 2020-2025
Europe	380.2	380.0	443.3	656.0	1,045.4	22.4
APAC	270.2	286.0	348.9	562.2	970.6	27.7
Americas	255.8	266.3	322.3	513.2	880.0	27.0
MEA	134.5	137.0	162.0	246.1	401.8	24.0
Total	1,040.7	1,069.3	1,276.5	1,977.5	3,297.8	25.3

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Table 7: Global Market for BIPV in Commercial Buildings, by Region (USD Million)[98]

Region	2019	2020	2021	2023	2025	CAGR% 2020-2025
APAC	579.2	595.3	706.2	1,079.2	1,773.9	24.4
Americas	289.1	296.0	352.2	542.4	899.7	24.9
Europe	285.9	289.1	341.1	516.6	842.8	23.9
MEA	77.4	78.6	92.9	140.7	229.1	23.9
Total	1,231.6	1,259.0	1,492.4	2,278.9	3,745.5	24.4

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Table 8: Global Market for BIPV in Industrial Buildings, by Region (USD Million)[99]

Region	2019	2020	2021	2023	2025	CAGR% 2020-2025
APAC	640.7	640.0	737.2	1,061.30	1,640.2	20.7
Europe	415.3	420.6	497.2	755.3	1,236.2	24.1
Americas	296.9	304.1	362.1	558.3	927.1	25.0
MEA	170.1	168.0	192.7	275.3	422.3	20.2
Total	1,523.0	1,532.7	1,789.2	2,650.2	4,225.8	22.5

Note: The base year is 2019. Estimates for 2020-2025 are projected.

3.1.3 GLOBAL BIPV MARKET AND REGIONAL SEGMENTATION

The unique abilities of BIPV to be both visually appealing and provide a source of renewable energy is driving interest from architects, builders, building owners, electricians, building project developers, investors, and governments. While BIPV is established in some areas, it remains an emerging business sector for PV manufacturers. Much of the success in BIPV has been driven by government policies that created headroom for industrial growth and incentivized the use of these materials—feed-in tariffs (FITs), rebates, renewable portfolio standards (RPS), solar renewable energy certificates (SRECs) and minimum solar-generating capacities for utilities have all contributed to the success of this market.

However, the BIPV market is made up of several niches, which has been a core challenge in this area. PV technologies that make it possible to make every structure on earth a power station exist, and while some of the products needed to serve the BIPV market sub-segments are available (from a quantity, industrial capability, marketing, partnering and installation perspective), a ramp-up is still needed.

Table 9: Global Market for BIPV, by Region (USD Million)[100]

Region	2019	2020	2021	2023	2025	CAGR (2020-2025)
APAC	1,490.10	1,521.30	1,792.30	2,702.70	4,384.70	23.60%
Europe	1,081.40	1,089.70	1,281.60	1,927.90	3,124.40	23.50%
Americas	841.8	866.4	1,036.60	1,613.90	2,706.80	25.60%
MEA	382	383.6	447.6	662.1	1,053.20	22.40%
Total	3,795.30	3,861.00	4,558.10	6,906.60	11,269.10	23.90%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

In terms of overarching barriers in the BIPV market, several surveys show that one of the most significant barriers to the implementation of BIPV systems is the biased perception of their economic feasibility. This perception is twofold: the higher upfront cost, and the lower irradiation reaching the vertical part of the building (even in the absence of shading from the surroundings) have hindered the perception of these technologies as beneficial and cost-effective. While BIPV has seen a substantial reduction in PV module cost over the past eight years, the message of better value has not yet reached planners and developers.[101] Another perception hindering growth of BIPV is lower flexibility in design and aesthetic considerations – architects may find BIPV visually unattractive, and this affects their attitude when designing and projecting a building. However, BIPV modules are available in almost every color, including pure black and pure white, and any design can be added using digital printing of the front glass.[102]

In terms of factors that are driving growth in the BIPV market, BIPV systems can be tailored to a large variety of building projects and contribute significantly to renewable energy systems with current technological design options. The following factors are seen as important for driving future growth:

- An increase in flagship demonstration projects to increase visibility and long-term experience with BIPV
- Facilities for customized, but highly automated production
- Innovative business models for future renewable energy systems
- Simplified and harmonized regulations
- Increased digitalization of the entire value chain[103]

These factors would be very helpful for the construction sector, in general, and BIPV technology, as adoption requires higher visibility, familiarity with the concept, and smooth, high-quality assured communication between the different trades and throughout the entire construction process.[104]

The following sections provide a look at the BIPV market in the regions of interest: Europe, Asia, and the United States.

3.2 EUROPEAN MARKET SIZE & TRENDS

Until recently, Europe was the largest PV market in the world (it was recently surpassed by China) and remains the area with the greatest installed PV capacity. That said, the pace of European solar installations is beginning to slow down as China, the U.S. and Japan increase installed PV capacity. Today China owns some of the PV production capacity located in Europe, with continued R&D activities in Europe and production moving to China. However, that shift will likely be curbed by newly imposed punitive tariffs for imports of PV panels from China and Taiwan.[105]

Europe is a steady market opportunity for BIPVs, which is partially due to the building materials used in the area. The prevalence of roofing tiles, their replacement cycle, local ordinances that require harmony with existing structures and localized emphases on BIPV roofs all contribute to the solar roof tile market. The major problem of BIPV on traditional historical buildings (THB) is the visual impact determined by the color of the photovoltaic cells that affect the level of the overall insertion on valuable casings and traditional materials, but BIPV applications with high integration and almost no visual impact are already on the market. Window-Integrated Photovoltaics (WIPV) and other glazed surfaces are also important products to integrate into THBs.[106] The institutionalized EU mandate for increasing uptake of renewable energy technologies, national FITs that favor BIPV installations, and the rise of technologies that can mimic THB materials through the color and shape of clay roof tiles have helped to secure this market.[107]

The largest European countries offer the best opportunities for BIPV, and Germany remains at the top of the list due to the presence of a large number of PV companies that are engaged in BIPV product production. Across the globe, partnerships and associations with architectural firms, tile manufacturers and installation companies are key success factors in this market. Individual incentives will be discussed later in this report, but strong incentives and policies in the EU, and specifically France, Germany and the U.K. are crucial to success in this area. The most favorable EU member states for pursuing BIPV projects are, in descending order, France, Italy, the U.K. and Germany, based on the magnitude of the feed-in-tariff (FIT) payment offered per kW for BIPV. France offers central government subsidization of 50% of the cost of a BIPV installation, which is more generous than others.[108]

The Zero Energy Building Mandate (NZEB) mandates that all new buildings in Europe be nearly zero-energy buildings (NZEB) by using renewable fuels, geothermal, solar heat and renewable electricity generation technology such as PV, either as an add-on or BIPV, or a nearby renewable energy project. Furthermore, the NZEB mandate is encouraging glass and building cladding materials companies to accelerate the development of products that contain a PV capacity. With the NZEB regulation coming into force in 2020, architects and builders were prepared for green technologies coming into play. One area that has been highlighted for potential in meeting and maintaining NZEB efforts is lighting, which makes up approximately 10% to 20% of a building's energy consumption. This may lead to future growth in skylights, and the inclusion of a PV capability in skylights and breezeways. This is believed to be an inevitable step to temper solar heat with shading, and to generate power to offset cooling and lighting demands.[109]

In terms of technical considerations impacting the adoption of BIPV in Europe and elsewhere, BIPV installations will be sized to fit on a building, therefore, even with maximum output, these installations will constrain the value of the PV output to retail price from the grid. With respect to Europe, the retail price of electricity ends up being multiple times the cost of electricity generation, therefore, PV manufacturers are generating interest from various building component manufacturers whose products include ceramic, cement, slate and metal roofing tiles. The purpose of the engagement would be to incorporate the PV technologies into the building components themselves.[110]

These relationships are important, as different locations provide different incentives based on different parts of a building and different materials. For example, the European BIPV market demands that the PV capacity be embedded in the roofing material or glued down upon it directly. In this format it can be claimed that the PV component replaces overspray that is used to seal single-ply roofs. These requirements have helped shape work carried out by European PV manufacturers and research institutes who have been devising ways to meld PV technologies into the built environment for decades. It is widely acknowledged that Europe has become a central location for the development of new PV materials, and experts believe that the companies that perform best will be the ones that match products visually with existing building appearance and those that invent new, broadly applicable forms of BIPV systems. Aesthetic appeal is still within the easy reach of the various manufacturers of both PV capacities, BIPV adaptations of the technologies and manufacturers of exterior building components.[111]

Additional factors that have boosted BIPV adoption and inclusion in the region, such as the rebound of the construction industry in Spain and the United Kingdom. Spain had drawn back and canceled FIT programs. The Spanish building industry is very important due to its location, the country's historic preference for tiled roofs, and a PV industry that is always looking for financially viable and technically sound options. The U.K. had established a FIT program that at first encouraged the development of bulk power solar farms on the ground and then tweaked the program to encourage on-building projects. To further drive growth in this space, PV and BIPV partners will need to be prepared for spurts of building and renovation/replacement activity. Analysts note that the U.K. is expected to remain a mainstay for several years unless the government moves away from its support for renewables in favor of centralized power systems such as nuclear power and shale gas-fueled turbines.[112]

Another budding market opportunity for BIPV is the growing number of flat, energy-efficient metal roofs with the move to solar affixed to these materials being encouraged by the German, French and U.K. governments. Growing suburbs with sports stadiums and large shopping malls require extensive construction and renovation of car parking structures, as do most of the major airports throughout Europe, which is expected to be one of the strongest BIPV markets in Europe for decades to come.[113]

Growth in the EU market for BIPV equipment will be growing at a relatively rapid pace but will still be constrained in the near- to mid-term by the slow rate of recovery from COVID-19. While the business remains, there is a focus on the cost of any new building and renovation since not all desirable additions are affordable if the payback extends more than a few years. Furthermore, bank financing may be problematic if a building improvement serves a different function, with the risk of an electrical fire from a roof sited BIPV capability entering loan and mortgage considerations at a time when lenders are being ultraconservative.[114]

Table 10: European Market for BIPV, by Application (USD Million)[115]

Application	2019	2020	2021	2023	2025	CAGR (2020-2025)
Roofing	514.2	539.7	656.9	1,056.7	1,827.1	27.6%
Facades	326.4	321.0	366.1	516.2	780.9	19.5%
Architectural Shading	138.0	136.3	156.1	220.6	332.2	19.5%
Glazing	102.8	92.7	102.5	134.4	184.2	14.7%
Total	1,081.4	1,089.7	1,281.6	1,927.9	3,124.4	23.5%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Table 11: European Market for BIPV, by End User (USD Million)[116]

End User	2019	2020	2021	2023	2025	CAGR (2020-2025)
Industrial	415.3	420.6	497.2	755.3	1,236.2	24.1%
Residential	380.2	380.0	443.3	656.0	1,045.4	22.4%
Commercial	285.9	289.1	341.1	516.6	842.8	23.9%
Total	1,081.4	1,089.7	1,281.6	1,927.9	3,124.4	23.5%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Another important factor to consider with BIPV installations in Europe is the cultural context. Europe has much older, sometimes ancient, buildings that are intermingled with newer metropolitan high rises and broad-roofed commercial & industrial (C&I) solar installations. Given that aesthetics and history can be key elements during major replacements or renovations of treasured existing buildings a strong preference is often placed on preserving the historic appearance of old buildings, while various means are considered to encourage large-scale PV installations in the built environment. In addition to aesthetic and cultural/historical preferences, many different regulations also come into play in this area, however, they include the consensus view that local renewable power generation is beneficial, and regulators provide guidelines for the targeted application of BIPV technologies. For example, roofs that are invisible to the public are all candidates for replacement BIPV roofs, but when roofs are visible to the public, it is necessary to install BIPV roofs that faithfully mimic the former finish. Likewise, BIPV glazing products must also maintain the look of normal windows when the windows are replaced but can have an innovative appearance on new buildings.[117]

The SolarPower Europe's *EU Market Outlook for Solar Power 2020–2024* reports that, "*State aid has been instrumental to improve the cost competitiveness of solar and kick-start the solar PV market in Europe*."[118] As such, utility-scale solar installations are competitive with fossil fuels in most countries and subsidy-free solar PPAs develop at a fast pace throughout Europe. Moving forward, the energy and environment state frameworks must keep pace with change and address new challenges such as the support of innovative solar technologies (AgriPV, floating solar, BIPV), storage, and renewable hydrogen. In October 2020, the European Commission's Executive Vice-President for Competition launched a call for contributions of stakeholders on the compatibility of European Competition policy with the European Green Deal, touching on the three main pillars of competition policy – State aid control, antitrust rules, and merger control.

As noted in the *BIPV Market and Stakeholder Analysis* published by the European Commission, several studies have been carried out to explore the drivers of the interest for BIPV solutions. For example, the Horizon 2020 projects Dem4BIPV and PVSITES looked at this issue on a European scale. The figure below presents the results of a survey conducted for the Dem4BIPV project, which teamed up with leading universities in Europe to train BIPV professionals and investigated BIPV market drivers.

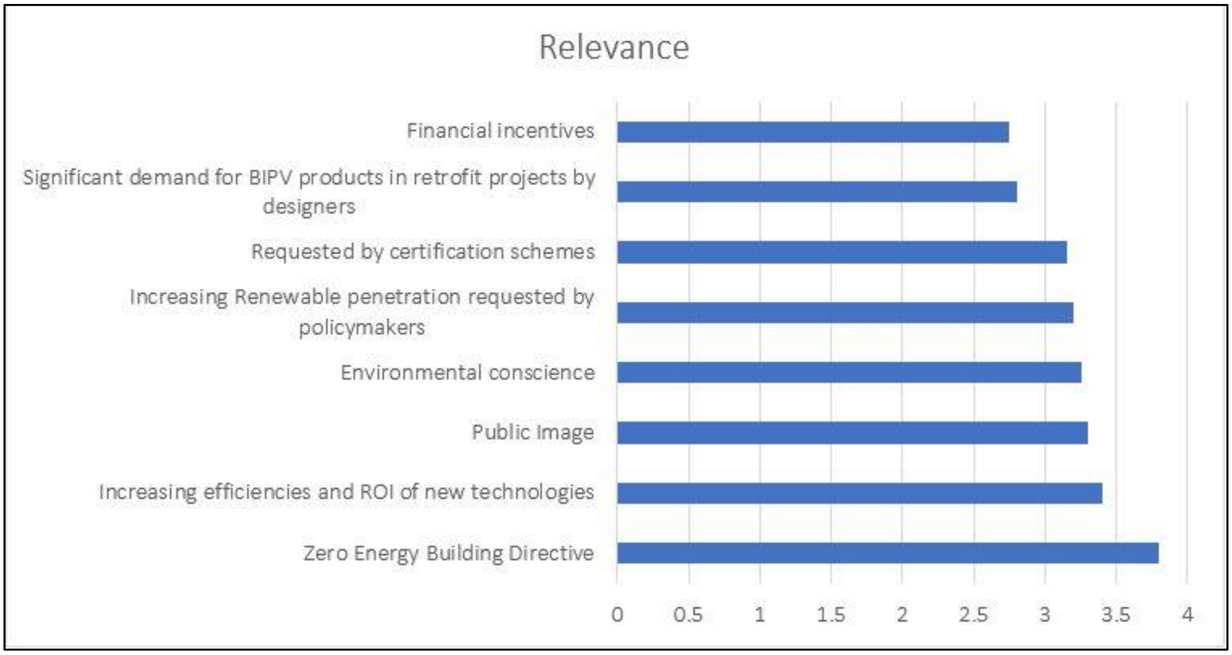


Figure 10: Key Market Drivers (1-Low Relevance 5-High Relevance)[119]

While there is a phase-out of BIPV specific incentives, business models for BIPV are more reliant on optimized self-consumption ratios. Based on past studies and understanding of the BIPV market and industry, the BIPVBoost analysis indicates that the market is driven based on an increase of intrinsic attractiveness for the technology and more favorable market conditions. These drivers can be summarized as follows:

- Cheaper PV system components
- Systemic innovations leading to improved competitiveness (e.g. higher PV cell efficiency, lower system losses, and improved reliability of BIPV elements)
- Better aesthetics and customization possibilities of BIPV products
- A wide range of product manufacturers, which stimulates competition
- Increasing regulatory pressure to increase the sustainability of buildings
- A “green” and sustainable aspect, which is increasingly valued by building owners and occupants[120]

Despite the effects of these stimulating factors, barriers to further deployment of BIPV still exist. These remaining obstacles have been summarized in the table below and split in four categories.[121]

Table 12: Summary of Barriers to the Deployment of BIPV Solutions[122]

Structural & Regulatory	Economic	Technical	Socio-Psychological
Lack of collaboration between stakeholders: PV, construction and real estate sectors do not communicate enough	Additional cost of BIPV compared to BAPV and regular construction material which can be discouraging	Lack of field data on degradation level and system performances	Lack of knowledge among professionals of the construction sector
Complex and inappropriate regulatory framework	Lack of possibilities to monetize PV electricity production	Lack of standardized products (e.g. mounting systems)	Lack of awareness among the public
Unstable regulatory environment, such as unexpected modifications and retroactive measures	Lack of valorization of renewables in the built environment	Lack of clearly defined maintenance procedures	Aesthetical possibilities of BIPV elements are still too limiting for some architects
Lack of standards and codes combining PV and building requirements	High up-front cost and long-term payback	Ability of some buildings' structures is insufficient to carry BIPV elements' weight	

3.3 EUROPEAN POLICIES & INCENTIVES

In recent years, governments across the globe have initiated several measures to support the growth of renewable energy technologies, including BIPVs. This section provides an overview of major government initiatives and examines both BIPV-specific and general renewable energy policies in Europe. Many different forms of policy support for renewables have been added over the past decade and have been supplemented or extended to keep pace with innovation and change. In addition to global, national, and regional policies, city and local government policies remain a growing segment of the policy landscape.

By 2050, solar energy is expected to become Europe's prime energy source, with the potential of supplying more than 60% of Europe's total energy demand.[123] Policies and incentives for BIPV in Europe date back more than fifteen years and have been led by France and Italy where feed-in-tariffs (FITs) were introduced in 2006 and 2007 respectively and the market began to mature in 2009.[124]

From a broad policy perspective, the FITs for renewable energy sold into the utility grid have been put in place across the EU and on a local level – this is seen as driving a substantial generating capacity from renewable energy sources within a set area. However, rules set forth by the European Commission (EC) mandate declining subsidy schemes for renewables projects above 1-3 MW – anything below this level that continue to receive subsidies. However, this is seen as a disincentive for BIPV given the typical scale of projects and the potential for developers to lose out on subsidies when projects are completed at a large scale.

While the BIPV market is approached from a regional perspective, individual countries use different definitions of BIPV, therefore, there is no "standard" definition, but European standard EN 50583 is the most common, internationally accepted definition. In addition to variance in, but adherence to common definitions, certain technical standards have also been established for BIPV in Europe – these vary by country, but a core group of standards are applied on a regional level.[125] The European Commission published its "Clean Energy for All Europeans" initiative in late 2016, which includes eight different legislative acts:

- Energy Performance in Buildings Directive (EPBD)
- Renewable Energy Directive (RED)
- Energy Efficiency Directive (EED)
- Governance Regulation
- Electricity Regulation
- Electricity Directive
- Risk-Preparedness Regulation
- Regulation for the Agency for the Cooperation of Energy Regulators[126]

Presently, France, Germany and Luxembourg have the strictest regulations regarding incentives for PV on buildings, which has accelerated the appearance of BIPV in these countries.[127] These policies and progress meeting targets is explored by country and for the region as a whole in the D9.2 Regulatory framework for BIPV document.

In September 2020, the European Commission (EC) unveiled the Renovation Wave strategy, which aims to reduce building emissions by 60% by 2030, through doubling the rate of energy renovation in Europe, and should trigger the renovation of 35 million building units by 2030. The Renovation Wave is looking to provide an integrated approach to building renovation, while acknowledging the contribution of on-site renewable solutions and rooftop solar to achieve higher energy efficiency requirements, and secure affordable electricity supply for vulnerable consumers. Generally speaking, this effort, and others associated with it aim to combine good design with sustainability.[128]

SolarPower Europe's EU Market Outlook for Solar Power 2020–2024 notes that in the current complex political landscape, three initiatives will be key to unlocking the potential of on-site solar in buildings:

- "The proposal, as part of the revision of the Renewable Energy Directive, to introduce minimum requirements for renewable energy in buildings.
- The commitment to map existing challenges encountered by BIPV products in the EU and to address by BIPV, such as facilitating mutual recognition of national certification schemes and insurance schemes.

- As part of the revision of the General Block Exemption Regulation and the Energy and Environmental Aid Guidelines (EEAG), the Commission will clarify the scope of State Aid for renewable energy installations for self-consumption."[129]

Presently, the EU is shifting towards a new approach to competition policy and State aid to help the region accelerate its green transition to reach climate neutrality and ensure the fast and large-scale deployment of key technologies.

Per the "Building Integrated Photovoltaics Declaration,"[130] the European Union should focus on five key priorities to maximize benefits in this area:

1. **"Market pull**: Expanding the size and depth of the European and global markets is central to secure a prosperous European solar construction products industry. It helps generating investments of scale and enables further cost-reductions that increase the global competitiveness of the industry.

2. **Industrial Strategy**: Adopting "a more strategic approach to renewable energy industries," such as the solar construction product industry, will be key to meet the objectives of the European Green Deal and ensure the decarbonization of the EU's building stock.

3. **Standardisation**: Delivering a real Single Market for construction products is crucial to open new market opportunities and support the competitiveness of the European BIPV industry.

4. **Innovation and Training**: As a cutting-edge set of technologies, solar construction products will be at the forefront of innovation within the PV and construction industries. Technological advances will increase electricity production, further reduce costs and enable the mass customisation of solar construction products.

5. **Circularity**: The European industry for solar construction products is committed to ensure that the products it manufactures correspond to the highest standards of sustainability."[131]

In addition to broad-strokes policies and incentives to encourage green and renewable technology development and usage, two policy programs that have been instrumental to BIPV development and implementation: BIPVBOOST and PVSITES.

BIPVBOOST is looking to provide market opportunities at a world-wide level for the European photovoltaic and construction industry by developing highly efficient and multifunctional energy producing construction materials, reducing costs associated with these materials, and maintain flexibility of design, high performance, long-term reliability and design aesthetics.[132] This will be achieved by using short and medium-term cost reduction roadmaps addressing the whole BIPV value chain and demonstration of the contribution of the technology towards mass realization of nearly Zero Energy Buildings.

As part of this initiative, BIPVBOOST is developing technical solutions to foster building-integrated photovoltaic (PV) applications in buildings. The different innovations are shown in the table on the next page.

Table 13: BIPVBoost Innovations[133]

Manufacture	Modules	Digital Process & EMS	Building Skin Solutions
Tabber-welding for c-Si,	Ventilated façade solution with colored c-Si based cell	BIM-based tool supporting process design, manufacturing and installation	Multifunctional BIPV opaque façade cladding solution
Tabber-welding for back-contact cells	Skylight glass, ventilated facades and curtain wall with a-Si patterning solutions	Cloud-based BEMS including demand response and storage management	Enhanced frameless façade systems with CIGS on metal modules
Self-configurable string lay-up equipment	Bifacial modules for balustrades, walkable floors and curtain wall with back-contact cells	Fault detection and diagnosis tool	Enhanced roof and façade systems with CIGS on metal modules
Semi-manual string interconnection station		Augmented reality app for pre-design stage	Glass-glass plug & play façade systems.
Automatic and self-configurable in-line electroluminescence quality control			

The figure below illustrates the three project phases for BIPVBoost.

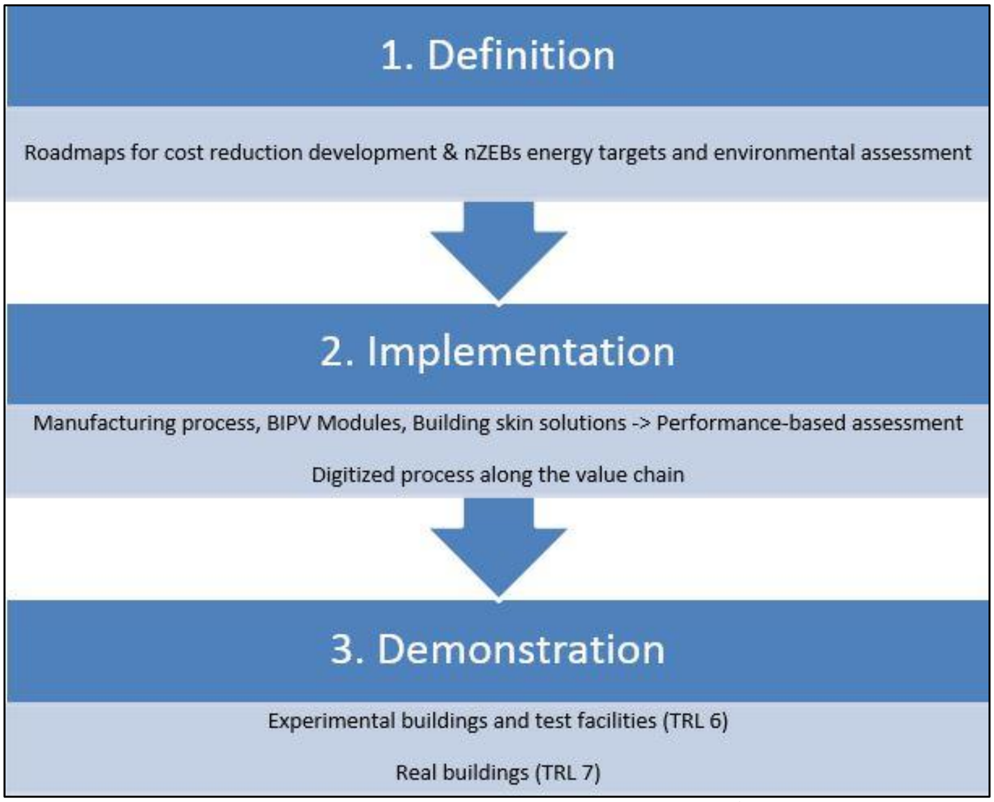


Figure 11: BIPVBoost Project Phases[134]

PVSITES' goal is to drive BIPV technology to a large market deployment by demonstrating a cutting-edge portfolio of building integrated solar technologies that meet market needs. This project is open to and targeting professionals from the BIPV and construction sector including architects and engineers, Industry Associations & Policy makers, and the Academic and scientific community. These groups will address the following challenges facing BIPV adoption with targeted solutions:

- "The challenge of enhanced flexibility of design, outstanding aesthetical value and increased performance.
- The solution: a wide portfolio of BIPV products based on crystalline silicon and CIGS photovoltaic technologies complying with market requests.
- Fostering synergies between multifunctional BIPV systems and other functional building elements.
- The solution: Low concentration and passive solar control BIPV system.
- The need for a software tool for the joint simulation of BIPV products and building energy performance.
- The solution: An accurate, user-friendly, integrated software tool for performance prediction of BIPV (and also building adapted) products and their impact on building energy performance will be developed.

- The need for a solar BIPV generation more predictable, manageable, grid-friendly and profitable in terms of building energy savings.
- The solution: A combination of flexible and high efficiency grid interface for BIPV systems and new building energy management strategies will be developed.
- The need to demonstrate reliability of advanced BIPV solutions by effective incorporation onto real buildings.
- The solution: high impact demonstrations in real buildings and experimental facilities throughout Europe."[135]

3.4 ASIAN MARKET SIZE & TRENDS

Countries included in the Asia-Pacific (APAC) region already make-up a market that is in a bit of a BIPV boom for both commercial and non-commercial reasons. Today the market in APAC is more attracted to BIPV roofing solutions because tile roofing is common in the densely populated residential markets of China, Japan, the Philippines and South Korea, and concrete slab roofs, which are also popular in the region, offer an attractive support base for PV panels. Additionally, the region is home to some of the largest BIPV industry players as well as hundreds of small players - the presence of these players contributes to the growth of the BIPV market in the region.[136]

Furthermore, hundreds of certified green buildings have been built in Asia with hundreds more going through the LEED certification process. India, Indonesia, Malaysia, Thailand and Singapore, are home to the majority of these buildings.[137]

Table 14: APAC Market for BIPV, by Application (USD Million)[138]

Application	2019	2020	2021	2023	2025	CAGR (2020-2025)
Glazing	636.9	668.6	804.3	1,264.3	2,138.7	26.2%
Roofing	534.2	536.9	625.6	920.7	1,453.3	22.0%
Facades	227.8	228.2	265.1	387.8	608.2	21.7%
Architectural Shading	91.2	87.6	97.3	129.9	184.5	16.1%
Total	1,490.1	1,521.3	1,792.3	2,702.7	4,384.7	23.6%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Table 15: APAC Market for BIPV, by End User (USD Million)[139]

End User	2019	2020	2021	2023	2025	CAGR (2020-2025)
Commercial	579.2	595.3	706.2	1,079.2	1,773.9	24.4%
Industrial	640.7	640.0	737.2	1,061.3	1,640.2	20.7%
Residential	270.2	286.0	348.9	562.2	970.6	27.7%
Total	1,490.1	1,521.3	1,792.3	2,702.7	4,384.7	23.6%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

On a country level, China emerged as the largest global PV consumer over the past few years. The country has the most polluted air on the planet and is making considerable efforts to change this. Beginning in 2005, the Chinese government's policy on renewable energy industries, particularly wind and solar, evolved as these technologies proved to be mass-producible, exportable (especially PV products) and a significant source of domestic employment. Today, China has emerged as the world's largest consumer of new wind turbine and solar capacity and produces approximately 80% of the world's PV modules.[140]

By shifting to renewable energy, the government shut down thousands of coal-fired power plants to clean up the air pollution. Wind energy and large PV power plants have increased and there is a growing emphasis on bringing PV into the built environment, particularly Shanghai and Dezhou (known as the new "Solar City"). Efforts include programs to put solar power on hundreds of thousands of state-built small houses in rural areas of the country, in Shanghai every building must have a green roof, and all buildings in China must significantly reduce their energy consumption footprint.[141]

In support of these efforts, China developed a policy that will require all new buildings to conform to Chinese-specific energy guidelines (similar to LEED specifications) and an initiative to rebuild 50% of the residential high-rise buildings to make them more modern, energy-efficient and functional. It is expected that mandatory inclusion of PV capacity will be required soon as its PV factories are preparing to sustain gigawatt-scale production of PV capacity for very large solar farms in northwest China.[142]

The Chinese population is seen as accepting toward government-mandated inclusions of solar and is supportive of building construction programs for both residential high-rise and urban corporate skyscrapers. Of note, China has had the largest near-continuous building boom in the world; its new residential buildings have the lowest occupancy rates; and most city skyscrapers are built to be as modern as possible. This is a significant difference from other regions which focus on BIPV for historical buildings and areas. Today in China, many of the new high-rise residential buildings have rooftop solar, but few are being equipped with BIPV facades. New building construction activity that can, and does, offer BIPV shading opportunities include municipal and public buildings, green parking garages and urban corporate towers.[143]

BIPV products are mainly used in China's urban construction of office and commercial sectors as well as in industrial zones, especially those with PV companies. It is believed that there may be more than 1,000 PV manufacturers in China alone. Presently, green roofs and green buildings are very popular and many new state-funded buildings with BIPV components are being constructed in China. This queue of projects is seen as a way to underwrite product development for export, especially given that the pace of new construction cannot last. In China, and elsewhere, residential buildings are not usually built with BIPV as part of the design, and the most common new buildings with BIPV glazing components are public and government buildings, greenhouses in the agricultural sector and institutional buildings. Additionally, green parking garages are a high-growth segment due to government requirements for the construction of new parking facilities for at least 2 million more vehicles in Beijing and Shanghai.[144]

In China, Government-owned, partially-owned and public-privately owned super companies have been becoming vertically integrated into the PV field at all product manufacturing stages - from mineral extraction to marketing and sales of PV products. It is expected that the Chinese government will begin to subsidize BIPV-specific projects to ensure low unemployment in the country. The BIPV modules are most likely to be used for refinement of design, engineering and installation routines since the goal is always to export products, but an equivalent environmental benefit will result from a project-by-project diminution of the GHG emissions that would otherwise occur in China.[145]

While low-cost solar cells and innovative small modules that can serve as roofing tiles are readily available in China, these products are not truly suitable for domestic applications where bamboo tiles or their composite equivalent are the incumbent and most prevalent roofing technology. Presently, the BAPV (Building Applied Photovoltaics) forms are more prevalent; BIPV roofing tile systems installed in China are expected to consist of one to two smaller systems for rural worker housing, which is already an established government program.[146]

In addition to its robust production capacity, China is viewed as having several other factors driving the success of its BIPV market including: state-of-the-art technology, global distribution channels, and a group of R&D laboratories focused on improving PV performance. China also has a large glass industry that can produce any commercial form of window or door glass. China produces consumes at least 30 million square meters of windows annually, which is a pace over three times that of Europe. The overwhelming majority of those windows presently go, first, to new high-rise apartment houses and condominiums and, secondly, to urban office buildings.[147]

Another target group for BIPV in China is the growing suburban home population, which unlike in Europe and the U.S., this market continued expanding through the global pandemic of 2020. This is seen as a strong indicator that China now has a sustainable internal economy that is not totally dependent on exports. Recent additions to the housing industry are prefabricated homes that include BIPV roofs and are site-adapted, designed, engineered and manufactured in China by vertically integrated super-companies and shipped for installation anywhere in the world.[148]

Japan’s cumulative PV installation target was 14 GW by 2020, a massive switch to renewables following the Fukushima Daiichi reactor disaster pushed the national PV total to over 9 GW capacity by the end of 2013, and in 2015, 10 GW in new PV capacity was attained. Large buildings (commercial, industrial, government) account for 13% of all PV installations in Japan, and residential accounted for 85% of the approximately 200+ MW in new capacity per year. Tiles are the most common residential roofing systems in Japan, just as they are in Europe.[149]

Among efforts to drive adoption and growth in this market the government established a generous FIT, and the Ministry of Land, Infrastructure, and Transport began buying PV systems for all types of government buildings. Under these programs, the most favorable market sectors for BIPV installations covered were retrofits and renovations of publicly owned buildings. Special attention was also placed on the Tokyo building market and the local/regional governments, which were attempting to outdo the national government in making their buildings solar powered. Of note, domestic manufacturers used to have twice as much PV manufacturing capacity as needed to meet the government's previous 2020 goals, but with new, more ambitious goals that some solar capacity will need to be imported for several years.[150]

Much like China, Japan has historically targeted many of its industrial products for the export market and was the world leader in PV manufacturing and export at one time. However, the country's PV industry was first overtaken by Germany, and then China, but the Fukushima Daiichi nuclear disaster in 2011 reversed this export trend. Solar power is now one of the cornerstones that the Japanese government is promoting to rapidly build new power generation to replace its aging and untrustworthy nuclear power fleet, therefore using more materials on the domestic front.[151]

In an attempt to bolster and improve its role in solar renewable energy Japan has established of a national goal of 53 GW of installed PV capacity by 2030, a goal that was in place before the Fukushima disaster and remains as one of the most ambitious programs in the world. Additional support programs include the inclusion of BIPV systems in existing central government and local/regional (prefectural) government buildings as well as new government buildings. Additionally, the federal government has continued subsidizing the development of a new market sector: planned communities with built-in solar capability. This approach is similar to what developers and PV vendors in the western U.S., particularly California, have carried out by involving national and regional residential development companies that include partial BIPV rooftops in their completed houses.[152]

Table 16: PV Power Installed During Calendar Year 2019[153]

		Installed PV capacity in 2019 [MW]	AC or DC
PV Capacity	Off-grid	2	DC
	Decentralized	1,123	DC
	Centralized	5,906	DC
	Total	7,031	DC
			Installed PV capacity in 2019 [MW] DC value
Grid-connected	BAPV	(1) Residential (<10 kW)	891.9
		(2) Commercial (< 50 kW, including ground-mounted)	2,119
		(3) Industrial	1,111

		(50 kW - 1 MW, including ground-mounted)	
		(4) Total of BAPV	4,121.9
	BIPV	(5) Residential (< 10 kW)	10
		(6) Commercial (10 - 250 kW)	20
		(7) Industrial (> 250 kW)	
		(8) Total of BIPV	30
	Utility-scale	(9) Ground-mounted (1 MW ~)	2,724
		(10) Floating PV systems	51
		(11) Agricultural PV systems	102 (including small-scale systems)
		(12) Total of utility-scale	2,877
Off-grid		(13) Residential	NA
		(14) Other	2,116
		(15) Hybrid systems	NA
		(16) Total of off-grid	2,116
Total		(17) Total ((4) + (8) + (12) + (16))	7,031,016

Other methods employed by the Japanese federal government are similar to those found in Europe, particularly through the use of ambitious goals and a substantial FIT for PV output.

Table 17: Japan's Feed-In Tariffs (FiTs) for the 2020 Japanese Financial Year (JFY2020)[154]

System size	Feed-in tariff rate (¥ per kilowatt-hour)
Systems below 10kW	21
Systems between 10kW and 50kW	13
Systems between 50kW and 250kW	12
Systems >250kW	N/A (competitive tender process held to determine prices)

The relatively high cost of renewable power generation and constraints related to grid access and capacity remain major challenges to the full integration of PV and BIPV energy. However, since FIT was introduced in 2012 solar PV has accounted for 94% of all renewable electricity capacity installations - total PV capacity grew almost thirteen-fold and had overtaken hydropower by 2018 with residential systems accounting for most of the PV installations. Larger projects have started to take off since the introduction of FITs, but the distributed segment (residential, commercial and industrial applications) remains the strongest driver, with commercial installations making up over 50% of yearly growth. Despite existing support from the FIT, all other renewable technologies have only shown modest growth over time.[155]

South Korea has committed to a major push toward green energy through government and industry efforts. BIPV is included with all PV in the country's installation figures, which are included below.

Table 18: Annual PV Power Installed During Calendar Year 2018[156]

		Installed PV capacity in 2018 [MW]	AC or DC
PV Capacity	Off-grid	-	DC
	Decentralized	176	DC
	Centralized	2,191	DC
	Total	2,367	DC

In terms of the incumbent materials, the most common roofing types for residential houses in South Korea are thatch, tile, wood or stone, all of which are amenable to replacement with BIPV tiles. However, only tile, stone, concrete, and metal can truly be matched with specially designed thin-film solar tiles. Of note, S-curve ceramic roofs were initially introduced into Japan centuries ago by Korean manufacturers and now the S-curve tiles are standard and have a little over 50% market share in both countries, although they are somewhat limited to residences owned by the middle and upper classes.[157]

In early 2020 the Seoul Metropolitan Government has become the first local government to announce its subsidy plan for BIPV buildings. Presently, the BIPV industry in Korea is led by a few companies such as ALUEnC, Eagon, and KCC Corp that research BIPV, produce the photovoltaic-incorporated building materials or install them onto buildings. ALUEnC is one, along with Eagon and KCC Corp.[158]

In early 2021 the Korean government announced that it would provide two billion won ($1.8 million) in initial subsidies to support building owners who wish to install BIPV, and p to 80% of installment costs will be supported. Furthermore, the Korean New Deal was announced in early 2021 to help provide recovery from the economic impact of the COVID-19 pandemic. As part of the Korean New Deal seven areas were announced, including BIPV, "Strengthening technology development for building-integrated PV (BIPV) installations and offshore wind."[159]

The Solar Energy Research Institute of Singapore (SERIS) was established in 2017 and is Singapore's national institute for applied solar energy research - it has been instrumental in the development of BIPV in the country. The government has also undertaken the BCA Green Mark Scheme, which is an initiative to create a more sustainable built environment in Singapore by promoting sustainable design, construction and operating practices in buildings. Several BIPV projects have been completed or are in process as a part of these efforts.

3.5 ASIAN POLICIES & INCENTIVES

Unlike in Europe, broad regional policies and incentives do not appear to exist in APAC, but individual nations provide their own policies and incentives for BIPV use and development. APEC's Energy Working Group (EWG) does undertake collaborative efforts and set regional goals, but it does not appear to provide a cohesive approach to shaping energy policy and efforts in the member states.

However, as noted earlier, China has the opportunity to become the global leader in BIPV technology by leveraging its existing PV industry and high rate of construction. According to reports, China's 14th Five-Year Plan could set new targets for BIPV, as well as implementing policies that help the growth of the PV industry such as subsidies, tax incentives and policies. For example, the 13th Five-Year Plan set a target for greening 50% of new buildings with some indicating that in the 14th Five-Year Plan the integration of BIPV in 50% of new urban construction with a particular focus on high-rise commercial and residential buildings should be the goal.[160]

A recent literature review indicates that *there are numerous barriers existing in the utilization of BIPV systems in China*, including a lack of consumer confidence in BIPV systems due to the high capital cost of purchase and installation, and later on-going cost in maintenance. The major problems restricting the rapid extension of distributed solar PV power generation are high initial investment (costs), difficulty in financing, and long investment payback periods. These barriers are often seen in other countries and regions, as well.[161]
Researchers note that, based on literature review, more studies should be carried out to identify the major barriers to adoption of BIPV applications in residential buildings in China. From a more localized perspective, a case study with a comprehensive survey has been carried out in Wuhan, China to identify the major barriers affecting the installation of BIPV system to residential buildings in Wuhan. These results indicate the following major barriers to adoption, "…knowledge, technology, economic, social and political barriers are the hurdles for BIPV adoption." [162] More demonstration residential buildings with BIPV systems should be built and residents should be invited to visit these demonstration buildings more frequently so that residents can appreciate the benefits of BIPV. Additionally, policy incentives for developers are seen as potentially beneficial based on this localized case study.[163]

Japan has taken a similar approach to Europe in its use of FITs to drive BIPV growth and adoption. Presently, FITs in Japan for solar PV systems are provisionally set by the national Ministry of Energy Trade and Industry (METI) and began in 2009, today the government targeting more than 130GW of deployed solar PV by 2030.[164] In addition to FITs Third Party Ownership (TPO) of PV systems is another approach to growing the use of BIPV – TPOS are being used by local governments for the lease of the roofs of public facilities. Crowd-funding is another method being pursued and is sometimes carried out through private and commercial firms. Installation of 10 to < 50 kW small-scale PV systems has advanced since the FIT program started in Japan, and this capacity range now boasts the largest PV installed capacity on a cumulative basis. Analysts believe that the growth of this market segment can be attributed to the fact that stable revenues from selling electricity can be secured, that it is easy to start the business with the low-voltage grid connection, and that tax-saving schemes are available.[165]

The following tables summarize key investment schemes and policy framework in Japan's BIPV sector.

Table 19: Summary of Existing Investment Schemes[166]

Investment Schemes	Introduced in Japan
Third Party Ownership (TPO) (no investment)	"Roof lease model" is available, which leases only the right of use of roofs. However, this business model has legal restrictions. A model to directly supply electricity without passing through transmission grids has started.
Renting	There are some cases where land is rented.
Leasing	It is easier for leasing to secure credit line than bank loans and the procedures are easier. It is not necessary to own excessive asset for a long time. The leasing model has been actively used for these reasons. Leasing is also utilized to support PV systems on farmland while continuing agricultural activities.
Utilization of taxation system	Taxation system which supports investment by small- and medium-sized enterprises (SMEs), mainly dealing with 10 - 50 kW small-scale projects for self-consumption.

Table 20: Summary of PV Support Measures[167]

	On-going measures in 2018 - Residential	Measures introduced in 2018 - Residential	On-going measures in 2018 - Commercial + Industrial	Measures introduced in 2018 - Commercial + Industrial	On-going measures in 2018 - Centralized	Measures introduced in 2018 - Centralized
Feed-in tariffs	Yes (purchase of surplus electricity)	Maintain mid-term price target until FY 2019	Yes	• Cut in purchase price • Tender scheme (≥ 2 MW)	Yes	-Cut in purchase price -Tender scheme (≥ 2 MW)
Feed-in premium (above market price)	No	No	No	No	No	No
Capital subsidies	No	No	There are subsidies for non-FIT applicant		There are subsidies for non-FIT applicant	

Green certificates	Yes		Yes		Yes (rarely used since FIT is more profitable)	
Renewable portfolio standards (RPS) with/without PV requirements	No	No	Transitional measures of the past programs are still valid	No	Transitional measures of the past programs are still valid	No
Income tax credits	Preferential tax treatment under the Act for Facilitating New Business Activities of Small and Medium-sized Enterprises • Intended for companies and individuals who file an income tax return on the blue form • Two options: immediate depreciation (100%) or 10% tax credit (until the end of March 2018) • Fixed Property Tax is reduced by 50% for three years					
Self-consumption	No	No	There are subsidies intended for PV for self-consumption purpose (FIT is not provided)		No	No
Net-metering	No	No	No	No	No	No
Net-billing	No	No	No	No	No	No
Commercial bank activities e.g. green mortgages promoting PV	There are various financing options as an extension of mortgage and home improvement loans. The interest rate is approximately 1.5-2.6%.		Many financial institutions offer financing options for PV systems with a capacity of 10 kW or more taking advantage of FIT. The case of corporate finance is not very different from usual business loan, however, there could be conditions such as maximum period of 20 years, no collateral nor consigner required, etc. There is a case to keep the electricity for selling as collateral. The interest rate is approximately 2-4%.			
Activities of electricity utility businesses	No	Obligation to equip devices to address output curtailmen t	• Obligation to equip devices to address output curtailment started in 2015 • There are cases where electric companies or their subsidiaries carry out the PV power generation business • In the areas such as remote islands and places where power distribution capacity is saturated, demonstration tests were started to realize both the introduction of renewable energy and stable management of electric grids.			
Sustainable building requirements	Based on the "Act for the Improvement of the Energy Efficiency Performance of Buildings" promulgated in July 2015, a gradual change to conformity obligations to energy efficiency standards is promoted. Previous non-binding obligations were changed to conformity obligations for buildings with gross floor area of 2000 m^2 or more from FY 2017 onwards. As for buildings with gross floor area of < 300					

	m², it was scheduled to be obliged from FY 2020, but it was postponed. In case of conformity obligations, a building which primary energy consumption falls below standard as a result of assessment in a specific manner cannot be constructed. It is expected that installation of PV on buildings will increase through conformity obligations because PV is assessed as a device to reduce energy consumption.					
BIPV incentives	No	No	No	No	No	No
Other						

Singapore is an example of a country that has relied heavily on policy to drive the development and adoption of BIPV. As noted earlier that Singapore government launched several incentives to support policy such as the Building Construction Authority and Energy Market Authority provided financial support to incentivize the BIPV market. Researchers note that government policy support will have a great impact on the entire BIPV ecosystem, ranging from design support, product cost, installation to engagement and feedback from building residents and other end-users.[168] Today, solar energy harvesting only contributes about 2% of the electricity supply in Singapore, but the government is aiming to supply up to 15% of peak electricity supply with solar. One factor that is expected to positively contribute to this target is that, due to the land limitation in Singapore, PV modules on roofs have become insignificant in terms of promoting solar energy to the country, but BIPV modules can be integrated into the building envelope, such as building façades, roofs, balustrades, shading devices and skylights aligned with the trend of introducing biophilia and greenery. BIPV has the potential to efficiently capture solar energy over a larger surface area than the roof area, which is especially relevant in tropical countries such as Singapore and equatorial regions or countries where facades are exposed to direct sun rays for longer time (year cumulative) than in Europe or North America.[169] The *Journal of Sustainability Research* provides an overview of recommendations to stimulate BIPV growth in the country. In the next five years it recommends:

- Developing government-certified and user-friendly software applications for BIPV façade design 3D visualization and energy performance calculations.
- Developing training programs supported by the government.
- Establishing either tax rebates or incentives when integrating BIPV in façades.[170]

For the next 5-15 years, recommendations include:

- Government built pilot projects including residential high-rise development (HDB) to demonstrate the long-term value of glass BIPV façade systems.
- Showcase private sector projects including small scale architectural pavilions at building expos and events.

- Increase BIPV research and development (R&D) on chemical/material composite level and building integrated semitransparent photovoltaics (BISTPV).
- Ensure that there is plenty of R&D in the pipeline.[171]

3.6 AMERICAN BIPV MARKET SIZE & TRENDS

The discussion up to this point has largely explored the international markets for BIPV, with a focus on trends, policies, and incentives in Europe and Asia that are driving BIPV adoption in those regions. Here the discussion shifts to the U.S. market for BIPV. Research on the use of BIPV elements in the U.S. surfaced information pertaining to influential policies and incentives, advantages of BIPV, disadvantages of BIPV (hurdles that are hindering growth), and factors driving BIPV adoption.

BCC Research provides a breakdown of the American BIPV market. This includes both North America and South America, collectively. The American BIPV market is segmented by application, with roofing, facades, glazing, and architectural shading representing the key segments.

Table 21: American Market for BIPV, by Application (USD Million)[172]

Application	2019	2020	2021	2023	2025	CAGR (2020-2025)
Roofing	666.4	696.6	844.8	1,349.3	2,317.4	27.2%
Facades	85.8	84.3	96.0	135.3	204.3	19.4%
Glazing	30.3	27.7	30.6	39.7	53.9	14.2%
Architectural shading	59.3	57.8	65.2	89.6	131.2	17.8%
Total	841.8	866.4	1,036.6	1,613.9	2,706.8	25.6%

Note: The base year is 2019. Estimates for 2020-2025 are projected.

Roofing accounts for an 80.4% share of the American BIPV market (as of 2020), followed by facades (9.7% share of the market), architectural shading (6.7% share of the market), and glazing (3.2% share of the market).[173]

BCC Research discusses the U.S. market for BIPV, stating that the states with the highest incentives for PV include California, New York, New Jersey, New Mexico, Massachusetts, Pennsylvania, Maryland, Connecticut, Arizona, and Nevada. New PV programs are starting up in the southeastern states, New York, and the Gulf Coast states (except for Florida). The U.S. market tends to be more attracted to roofing products, within the context of BIPV. BIPV facades are attractive for use on buildings larger than single-family dwellings and these elements are most cost-effective when used on taller buildings.[174]

BIPV in the residential sector is somewhat constrained because a solar component is still largely viewed as an added cost—and builders and owners are very cost-conscious. The national average building integrated power generation capacity will need to increase while prices continue to decrease. With that said, there are a few locations in the United

States where utility rates are so high that it makes sense to have solar—the rate of return in some of these situations would be seven years or less in terms of payback, and then it would stay positive for around 20 years.[175]

Factors such as carbon taxes, utility rate increases, decreasing costs of PV elements, and an increasing number of PV subsidy programs are expected to drive the U.S. market for PV and BIPV, more specifically. Primary growth areas for new large and tall buildings include major cities such as New York, Boston, Dallas, Houston, Atlanta, Los Angeles, Seattle, and San Antonio.[176] The U.S. Green Building Council has made great strides and LEED certification is now standard among all levels of government (for public and private construction, as well as renovation). A significant amount of money is being spent to improve the efficiency of federal buildings and schools. The *American Recovery and Reinvestment Act (ARRA) of 2009* played an important role, as this legislation earmarked approximately $10 billion to support building energy efficiency.[177]

3.7 UNITED STATES POLICIES & INCENTIVES

The Department of Energy has expressed interest in better understanding the relationship between builders, roofing companies and solar PV installers. There are certainly factors that are encouraging roofing companies and builders to form relationships with solar technology installation companies. Among these factors include state mandates for solar energy. The most notable example is California. As of January 1, 2020, California building code (California Code of Regulations, Title 24, Part 6) requires all new construction homes to have solar panel technology. This change was brought about by the California Energy Commission, a key stakeholder in changing the California Code of Regulations to require residential solar power. While there are some exemptions to this law (if the roof is too small or the house is too shaded, for example), most new homes will have to adhere to this new mandate. There are tax credits and rebates available, but the anticipated cost is still substantial—between $8,000 and $12,000 per new home (even after tax credits and rebates are factored in). While the California Energy Commission has indicated that the average monthly mortgage payment will increase by approximately $40 per month, it is estimated that the average utility bill will be reduced by $80 per month, ultimately resulting in savings for the homeowner.[178]

Massachusetts may soon be following California's lead. Lawmakers in Massachusetts have proposed a bill (the Solar Neighborhoods Act, H.D. 3098) that would require rooftop solar on new homes, apartments, and commercial office buildings. A companion bill—S.D. 159—was also filed in the state Senate. A summary of the bill also stated that all new buildings would need to be solar-ready, or built in such a way that solar panels or other solar technologies could easily be added or retrofitted. In response to the bill's passage, the Department of Energy Resources (DOER) would amend the state's building code to "ensure that roofs are strong enough to support solar panels, that available roof space is maximized, and that buildings can make room for necessary electrical infrastructure."[179] Buildings may be exempt from this requirement if the roof receives too much shade, if a solar hot water system or other renewable energy technology is installed, or if the building has a green roof (i.e. vegetation). DOER may also grant exemptions to affordable housing developments.[180] In a single-family home, the solar energy system would have to produce enough energy to meet 80% of the energy demand for similar homes. DOER is expected to set minimum solar energy system requirements for other types of buildings.[181]

In addition to relatively new state-wide policies, there are also some local or city-wide policies in place. In November 2019, local laws 92 and 94 (part of the *Climate Mobilization Act*) took effect in New York City, mandating that any roof undergoing major construction be covered in either solar PV panels or a green roof system (a roof covered in vegetation). These laws will impact new construction projects, vertical and horizonal extensions, and projects involving major modifications to the roof (which would require a permit). This mandate places a financial burden of approximately $15,000-$20,000 on those building or buying new homes, or renovating existing homes. There may be exemptions for certain homes, such as those with very steep roofs and those that are structured in such a way that they would not be able to create the required 4 kilowatts of energy.[182]

According to the Solar Energy Industries Association (SEIA), there is a federal investment tax credit (ITC) for solar energy systems and this tax credit will be in place until December 31, 2023. Both residential and commercial customers can take advantage of this tax credit. It applies to three major types of solar technology—photovoltaic, solar heating and cooling, and concentrating solar technology.[183] In addition to this federal tax credit for solar, many states, counties, municipalities, and utilities also offer rebates and incentives for solar energy technologies. The Database of State Incentives for Renewables & Efficiency (DSIRE) is a key resource, as it provides a comprehensive list of solar incentives by state.[184]

While this program is not specific to solar, there is an Energy-Efficient New Homes Tax Credit for Home Builders, which provides an incentive of up to $2,000 to builders of energy-efficient homes (homes constructed prior to January 1, 2022 are eligible for this credit).[185]

3.8 SUMMARY

BIPV is implemented and planned during the design phase of building projects, but can be implemented as a retrofit through the end use areas of roofing materials, facades, and solar PV windows and glass. Presently, the roofing materials segment, which includes a variety of materials, is the largest segment of the BIPV market, but glazing, facades, and architectural shading continue to see growth. BIPV continues to be a nascent market as compared to solar PV, but factors impacting its growth include increasing societal familiarity with the concept, aesthetic, and benefits, improved technical capabilities for production and installation, business models and regulations that provide tangible incentives for renewable energy and BIPV targeting individuals, governments, and industry.

Europe and Asia have seen a more rapid adoption and integration of BIPV than the U.S. due to aggressive policies and incentives in those regions. In Europe, the Zero Energy Building Mandate (NZEB) had driven the renewable energy market, including BIPV, which has been furthered through the use of FITs and other policies. General market growth has driven the development of BIPV products that fit into the aesthetic and regulatory landscape of the area and helped to bolster their acceptance by end users. However, cost, planning, and customer preferences for incumbent materials remain obstacles to overcome across the globe. Similarly, the Asian BIPV markets have been driven by renewable energy targets, FITs, and other policies and incentives. The Asian markets have also benefited from a robust new construction sector that has been less negatively impacted by COVID-19 as well as domestic production capabilities and infrastructure for BIPV products.

This section also looked at BIPV and how it has been received in the United States. There are a few policies and incentives that may be helping to drive BIPV adoption. The requirement in California for most new construction homes to have solar technology is certainly an influential policy. Other states, such as Massachusetts, may be following California's lead. There are also local or city-wide mandates in place. In New York City, for example, local laws mandate that any roof undergoing major construction be covered in either solar PV panels or a green roof system (a roof covered in vegetation). These mandates will drive solar adoption and may also drive BIPV adoption as builders, architects, and key stakeholders working in these areas become more familiar with the solar technologies available.

4.0 Primary Market Research

4.0 PRIMARY MARKET RESEARCH

In an effort to learn more about the factors influencing BIPV adoption, we reached out to a number of individuals in multiple stakeholder groups, including those specializing in architecture, design and project management in the prefab home segment; architecture firms, MEP companies, and builders focusing on green engineering, sustainable design, energy-efficient buildings, or zero energy design; providers of BIPV products (including solar roofing shingles and tiles, integrated solar roofing systems, PV window coatings, and PV glass); and associations focusing on the building industry. In addition, we reached out to several companies and organizations providing BIPV modeling and simulation solutions to learn more about the capabilities of their software tools. The following sections summarize the feedback received from individuals in the prefab home, architecture/MEP, BIPV, and association segments, while the information gleaned from primary research with providers of PV/BIPV modeling and simulation tools is discussed in the *Modeling & Simulation Tools* section of this report.

Table 22: Primary Market Research

Affiliation	Contacted	Received Feedback	Response Rate
Prefab Home Companies	28	5	18%
Architecture Firms, MEP Companies, and Builders	19	2	11%
BIPV Product Providers	15	5	33%
Building Industry Associations	4	1	25%
Providers of PV/BIPV Modeling and Simulation Tools	21	11	53%
Total	87	24	28%

4.1 FEEDBACK FROM PREFAB HOME BUILDERS

With those specializing in architecture, design, and project management in the prefab home sector, our questions focused on the integration of BIPV elements: Are BIPV elements being considered when solar is desired for a home? What types of BIPV elements are seeing increasing interest or integration? What factors seem to be encouraging the adoption of BIPV (or even PV, more broadly) in the residential segment? Are there any major hurdles to adoption that need to be addressed?

One Owner and Architect for a prefab home company in California noted that the majority of their work is in the residential space and he is excited about emerging BIPV technology, but they have yet to implement anything meaningful in their projects. For the most part, he believes this is primarily a cost-related consideration. With the extremely high current costs of construction in California, he did not think that any of their clients would have a budget to support BIPV until the costs to implement these systems decreases dramatically. They are having challenges even getting clients to afford more than the most basic and minimal traditional PV systems required under the current California building codes.

A VP of Design for another prefab home company in California spoke to the installation of BIPV elements. Due to installation sequencing, it does not make sense most of the time to integrate roofing, as roofing is completed onsite. Other BIPV elements are not viewed as being affordable for most homebuilders. She is not seeing increasing use of BIPV elements in a factory environment or in the prefab segment at this time. They would love to see more product offerings, particularly as window shading elements that could be shipped along with the prefab components and installed onsite. Factors that seem to be encouraging the adoption of BIPV (or PV, more generally) include cost, ease of installation, and—for roofing products and panels—the ability to install the technology on a flat roof. There are a few hurdles that exist. Cost is certainly a concern. Any BIPV elements should easily integrate with other systems already on the market and they should be easy to attach to existing window and door frames (this is important for PV sun shading elements, in particular).

According to a Project Manager and Architect with a prefab home company in Ohio, they have never really given serious consideration to BIPV in one of their homes. They often deal with clients that are thinking of adding a standard PV array. Most—if not all—of their designs include a flat roof and it is simple enough to put a standard PV array on them. He felt that, at this time, BIPV seems too expensive to even consider—though he admits that they have never actually priced it out. In terms of major hurdles to adoption, he noted that price is the most significant hurdle. Personally, he is also hesitant to have PV integrated into the building materials. He would rather have the façade materials, for example, be the highest quality façade materials, in terms of aesthetics, maintenance, and durability. Adding the function of PV to that seems like one more thing that can go wrong. If part of the PV function fails, it is not simply a question of replacing that panel (as part of the standard array), but rather it could be an overly complicated process of replacing part of the actual building. He acknowledged that there might be systems out there that are modular and easy to replace—but if they exist, he is unaware of them.

An Energy and Sustainability Specialist with a prefab home company in New Hampshire stated that, at this time, they are not considering or integrating BIPV elements, primarily because of cost per square foot and wattage per square foot. PV panels produce more wattage per square foot and most of the cost comparisons that they have done do not show the additional costs of the BIPV elements to have the same ROI as panels, even when other building element costs are factored in. In terms of BIPV elements seeing increasing interest, they have had a lot of people asking for Tesla roof panels—she believes that Tesla's marketing has definitely opened more people up to this concept, despite it being around for so long. Unfortunately, Tesla roof panels are almost impossible to get right now and, again, in pricing and modeling exercises, PV panels tend to produce the most wattage per square foot most affordably. If solar windows were to become more widely available, she could certainly see some appeal there (cost and performance pending). She views cost, availability, and production as major hurdles to BIPV adoption. Right now, the only time they would ever look to these BIPV elements would be if rooftop solar PV was, for whatever reason, not an option.

According to a Chief Design Officer with a prefab home builder in Pennsylvania, her firm has not had any experience with BIPV products, to date. However, she is excited about this trend and hopes to see more BIPV integration in the future. Some of their homes have been designed to be "solar ready"—a process that they are still perfecting with the smaller factories they work with. They are also working on a PV package to offer to their clients (this would be PV panels on the roof, with optional battery storage). This package would be installed onsite. Integrating BIPV would require education (both for the design firms/builders and the factories they work with). She assumes that these products are currently cost prohibitive for their markets. In terms of BIPV elements that are seeing increasing interest or use, she noted that they have only had conversations with their solar provider about roofing materials. Their firm is definitely seeing an increase in homebuyer interest in PV systems. They have had a few customers install systems on their own, after purchasing the home. Those decisions have largely been driven by an environmentally centered mindset and a desire to reduce utility bills. There are a few hurdles that still need to be addressed. All stakeholders need to be educated on BIPV elements, they need to show up on the radar. This includes the prefab home companies and designers, factories, developers, GCs, and the homebuyers. She believes that a cost-benefit analysis would be important.

Table 23: Summary of Feedback from Prefab Home Builders

Questions	Summary of Feedback and Key Takeaways
Are BIPV elements being considered when solar is desired for a home?	To date, most prefab home builders have not implemented BIPV elements, but there is excitement surrounding BIPV and its potential moving forward. Cost per square foot and wattage per square foot have been cited as reasons why BIPV elements have not been used. Cost was mentioned as a deterrent by all of the people in this stakeholder group.
What types of BIPV elements are seeing increasing interest or integration?	Roofing seems to be the most common form of BIPV being considered—two respondents mentioned that they have had conversations with clients and/or solar installers about roofing materials. Tesla's marketing has increased awareness of BIPV and it has generated some interest in this segment. Those interviewed saw potential for PV windows (pending cost, performance, and availability) and window shading elements (these could be shipped along with prefab components and installed onsite).

What factors seem to be encouraging the adoption of BIPV in the residential segment?	Most respondents noted that they have not witnessed much adoption of BIPV in the residential segment (yet); however, cost, ease of installation, and the ability to install BIPV roofing products and panels on a flat roof are all factors that would encourage adoption. Tesla's marketing has been effective in generating interest in BIPV.
What are the major hurdles to adoption that need to be addressed?	Everyone mentioned cost as an issue, in one way or another. The cost of the BIPV elements is a hurdle, but construction costs are quite high, in general, right now. Many people who want or need solar are struggling to afford more than the most basic, traditional PV system. Some are simply under the impression that cost is a major issue—though not everyone has performed a detailed cost comparison. A cost-benefit analysis would be helpful. It should be easy to integrate BIPV elements with other systems already on the market, and it should be easy to attach BIPV elements to existing window or door frames—this is particularly important for PV sun shading elements. Stakeholders need to be educated on BIPV elements. Education and training would be beneficial for design firms, builders, the factories they work with, developers, general contractors, and homebuyers.

4.2 FEEDBACK FROM ARCHITECTURE AND EPC FIRMS

With those specializing in sustainable, energy-efficient, and/or zero energy design, architecture, and construction (this would include architecture firms and EPC firms, primarily), our questions were similar in nature to what was asked of the prefab home companies, but the focus was more on the commercial segment: Which BIPV market segments seem to be most compelling? Are certain types of buildings seeing increasing use of solar or BIPV? What BIPV elements seem to be most attractive for commercial applications? Which BIPV elements have the greatest level of interest? What are the major hurdles to more widespread BIPV adoption?

According to a Senior Principal focusing on sustainability within a large, international architecture, design, and EPC firm (the company has 350 offices around the world, with several in the United States), to date, she has not had any projects that have given a go-ahead for BIPV, mostly based on cost. For solar, they are seeing interest from all market sectors—commercial, mixed use, multi-family units, and industrial buildings. There is a lot of interest in solar, but thus far it is still heavily focused on rooftop solar. When asked about BIPV elements that seem to be most attractive for commercial applications or which elements are seeing interest from designers or building owners, she noted that the market is still trying to catch up with the idea of putting solar on buildings—more attention is being paid to just getting traditional solar onsite. They are still seeing interest in solar canopies, so this could be a promising application. Integrated roofing is expensive and roofing can be sort of tough in the sense that more people are now interested in occupiable roofs or green roofs (roofs with vegetation). Some may want to do a rooftop terrace or green roof, but then they could integrate solar somewhere else by using solar canopies or other shading elements. Cost, of course, was mentioned as a hurdle to adoption. However, the knowledge gap is also a considerable obstacle. A lot of people do not quite understand BIPV—what it means, what it looks like, what assembly looks like, etc. Most architects are very comfortable in their space, but this is very new and there is a clear knowledge gap. As an architect who does not know much about BIPV integration—who would they reach out to? There's just a lack of awareness. She has never even seen a real installation of BIPV, so knowing who to reach out to would be very helpful. Consultancies that specialize in both solar/BIPV and the building and architectural side would be helpful in terms of bridging the gap and helping key stakeholders in the architecture and design space feel more secure in terms of integrating BIPV.

We also spoke with a Principal who is with a top architecture firm in the San Francisco Bay area. In terms of compelling applications or types of buildings embracing BIPV, he noted that there is still a mindset in the community that solar—and especially BIPV—is expensive. They are not typically included when establishing project budgets and are easy targets for value engineering. They have had more success with clients who are designing buildings that they will continue to own and operate so they can benefit from the electricity cost savings over the long-term—examples include private schools, private clients building their own office space, etc. There are a number of BIPV elements that are attractive for commercial applications. Their firm has used solar panels to replace wall panels in one of their projects, which helped to offset the cost of the PVs. Roofing, glazing, and cladding all seem like attractive options, but they need more market-ready products. His sense is that BIPV products are still fairly custom and require additional effort from design teams—meaning that it would be more costly to design and construct the building. With regard to hurdles, cost and industry mindset were the top two obstacles that came to mind. A shift in industry mindset would be important, and this would include both designers and contractors—and especially the subcontractors responsible for the applicable trade(s).

Table 24: Summary of Feedback from Architecture and EPC Firms

Questions	Summary of Feedback and Key Takeaways
Which BIPV market segments seem to be most compelling? Are certain types of buildings seeing increasing use of solar or BIPV?	Solar, in general, is being increasingly integrated into commercial, mixed-use, multi-family units, and industrial buildings. There is substantial interest in solar, but it is still mainly focused on rooftop solar.
What BIPV elements seem to be most attractive for commercial applications? Which BIPV elements have the greatest level of interest?	There is interest in solar canopies and other shading elements because they would enable the integration of solar while leaving the roof free for other uses. Integrated roofing can be expensive and building owners are showing interest in occupiable roofs (like a rooftop terrace) and green roofs (those with vegetation). Solar canopies and shading elements let building owners have both solar *and* occupiable/green space. The other respondent noted that roofing, glazing, and cladding all seem like attractive options, but many people are under the impression that BIPV elements are fairly custom, requiring additional effort from design teams (this may translate to a higher cost for designing and constructing the building).
What are the major hurdles to more widespread BIPV adoption?	Both people that we spoke with in this segment reiterated that cost is one of the biggest hurdles. Both also mentioned the knowledge gap that exists, and issues with the industry mindset. BIPV elements are not typically included when establishing project budgets and they are low hanging fruit if cutting costs is necessary. A shift in the industry mindset will be important—for designers, contractors, and particularly the subcontractors responsible for the applicable trade(s). There is also a knowledge gap that exists. Architects and designers, in particular, may benefit from educational materials, resources, example BIPV installations, and consultancies that specialize in both solar/BIPV and the building/architectural industry.

4.3 FEEDBACK FROM BIPV COMPANIES

Conversations were held with individuals affiliated with five companies providing BIPV elements—including solar roofing shingles and other integrated roofing systems, as well as PV glazing, windows, and glass. The companies that we reached out to include CertainTeed, Tesla, GAF Energy, Luma Solar, SunTegra Solar, Lumeta Solar, Ubiquitous Energy, and Onyx Solar Energy. Our questions for this stakeholder group focused on factors that are driving and hindering the adoption of BIPV in the residential and commercial segments: What factors seem to be encouraging the adoption of BIPV in the residential and commercial segments? What do you see as the major hurdles to adoption? Are you seeing interest in BIPV in specific use cases or types of buildings? What are the most promising near-term targets for BIPV integration?

BIPV Roofing Company

In a conversation with a major provider of integrated solar roofing based in California, the person we spoke with noted that, at this time, they are only selling their solar roofing product in the residential market. They have not moved into the commercial market (yet). Their product is definitely better suited to residential homes. Part of the demand that they have seen has certainly come from Tesla's brand recognition—all of the BIPV roofing product companies we spoke with mentioned Tesla's influence, stating that it has generated an interest in BIPV, which has been beneficial for everyone in the segment. Customers who are interested in BIPV generally like it because of the aesthetic quality—aesthetics are important to them, but they also have that interest in innovation and sustainability. For some customers, integrated solar roofing is cost competitive with a traditional roof plus solar panels (this depends on the scope of the project, roofing materials, etc.). In other cases, the solar roof is more expensive.

With respect to hurdles, cost is a considerable obstacle. An integrated solar roof is still pretty expensive compared to a regular shingle roof with solar panels on it. Part of this increased cost comes from the complexity of installation and the complexity of designing the product (each home is unique). For every customer they work with, they have to do a custom design. It is also very hard to predict how long an installation will take or how complex a project will be—there are a lot of variables that are tough to predict. They are aiming to reduce the timeline for installing the product. Their product has roughly 400 parts that you could possibly combine on the roof—and each roof will need slightly different parts. Installation can be a complicated process.

With respect to where they are seeing adoption—because of the higher cost and the improvement in aesthetics, they are seeing more interest from high-end customers. There has been a lot of interest from new construction because it is nice for a customer to integrate solar roofing into their architectural plan. Homeowners have worked with their architect to design a roof that is compatible with a solar roof. While most of their interest is coming from homeowners, they also work with channel partners. These channel partners are generating their own leads and they may work with local builders and architects to find customers. The company has spoken with larger builders, but they do not have any larger-scale partnerships, it is mostly homeowners that are interested, and then the company will work with the homeowner's builder and architect. Right now, residential is a better fit than commercial. Some commercial projects have been quoted, but most have not opted to move forward because of the cost. There are more flat roofs versus pitched roofs. Part of the value is in the aesthetics. If you have a flat roof on a commercial building, that project would not benefit from the aesthetics. Also, the commercial utility rate is generally lower than a residential rate, so it is not as cost effective.

BIPV Roofing Company

We also spoke with an integrated solar roofing provider based in Michigan. They are seeing increasing adoption, interest, and public awareness surrounding BIPV, and solar roofing, specifically. The most significant driver is increased public awareness and knowledge that the product exists. Credit was given to Tesla, as their brand name and brand awareness sends a powerful message and gets people's attention. This company has seen an increase in product inquiries—substantially more interest from when they started. Increased knowledge and public awareness are key—but it is also important to note that about 90% of the increase they have seen has been in the residential segment (new construction, architectural, etc.). People want to have solar to be "green," offset energy costs, and they also like the look of integrated solar roofing.

With respect to hurdles, cost is far and away the most significant. Everyone that inquires about the product seems to love it, they want to buy it—but for those that do not ultimately buy it, the reason is primarily price. They have encountered some issues with HOAs—they are trying to keep solar out of "pristine" neighborhoods. Historic preservation projects present a similar issue. Another significant issue is that general contractors do not really understand the BIPV market—they see it as something that can slow down the sale. Solar integrators, if you ask them to look into BIPV, will most often talk it down because they are not as familiar with the product. They may view BIPV as a stumbling point. It would require additional knowledge and training. More progressive solar contractors—and sometimes even roofing contractors—will inquire about the integrated solar roofing product, but buy and large, contractor uptake is an obstacle.

In terms of near-term targets and use cases for BIPV, new construction seems to be promising. The roof is needed to begin with. This is not so much the case with average, middle income housing projects—they are not getting calls from these people. But custom homes are calling constantly because of public awareness and homeowners want energy independence. Custom new construction, particularly in the residential segment, is the biggest growth segment in BIPV. They also focus on customers looking to re-roof. There tends to be more interest in their product from projects with pitched roofs versus flat roofs. The significance of net metering policies also came up in the discussion. If the U.S. and all of its states can maintain good net metering policies, this will help the solar industry expand. In many cases, this has been a one-for-one credit—for every kW hour someone pushes to the grid, when they draw it out, it should be of equal value. As long as the customer does not take out more than what they put in, they do not have an energy bill. Utilities, however, are starting to push back on this and if that happens it will make the solar market less attractive. As long as net metering stays balanced, it is believed that the industry will flourish.

BIPV Roofing Company

According to a company developing and selling solar roofing shingles and solar roofing tiles in New York, factors encouraging BIPV (and in particular, integrated solar roofing) adoption include aesthetics, the "Tesla-factor," and the desire to get more power on a roof. With respect to aesthetics, people love the idea of solar, but they do not love the idea of solar panels on their roof (their own research has suggested that about 75% of people do not like the look of rooftop solar panels). People want to do more with solar, but they want it to look more natural and integrated. Custom homebuilders and other homeowners (those who are putting on a new roof) are interested in the product, but part of the issue is that oftentimes the company does not have a product dealer in their area. Tesla's brand recognition has had a positive impact, in terms of increasing awareness of integrated solar roofing—homeowners now know that this exists. Getting more power on the roof is also important to people. A smaller solar shingle product can better fill up the roof, enabling them to get more out of their solar installation.

Major hurdles to adoption include, of course, the cost of the product. Solar tariffs are also a problem, as this translates to increasing product costs. Companies have to keep revising their supply chain. Channel friction is also an issue. Roofers and homebuilders are not solar experts, they need a lot of support services and have to manage contractors. Solar integrators know how to do solar panels, but they have a hard time marrying an integrated product with their standard business, because integrated solar roofing only goes with a new roof and solar integrators are typically chasing every roof. The installation methodology is different and it is hard to have a crew do both. Solar integrators are seeing increasing interest from consumers, but the price point and logistics in selling it and getting it on the roof complicates their traditional business model. This company realized early on that they have to work with roofers and home builders, who are working with homeowners who will need a new roof. Roofers understand how to quickly put the system on, but they also have to work with an electrician to install it. The electricians play a key role here, too—if something goes wrong, this often traces back to an electrical issue or an error on the part of the electrician. With builders, they have to market their community as being "net zero" or featuring "green" homes.

In terms of specific use cases and other near-term targets, on the residential side they are seeing people who do not necessarily want solar panels, but they are building their dream or retirement home and want to make it unique and special. Sometimes people in HOAs or those who own historic buildings are worried that if they do not do it as a solar shingle, they may not get approval to add solar to the building or home. This company has also completed several commercial projects; sometimes the developer doing the project likes the integrated product. Slate roofs are good candidates because doing integrated solar with a slate roof can save money (slate roofs are quite expensive). There is a local law in New York City that is requiring carbon offsets for commercial new construction, so they have their first project driven by that in downtown Manhattan—a new high-rise building. They have mainly focused on sloped roofs, but they are moving toward exploring the side of buildings—shade structures, rainscreens, siding, and residential carports.

BIPV Glazing and Window Company

While integrated solar roofing has received a lot of attention and accounts for a significant share of the BIPV market, there are other types of BIPV solutions available. We spoke with a California-based provider of transparent PV window coating and PV windows. According to this company, you can put solar panels on the side of a building, and that technology works, but the major hurdle there is aesthetics. From an architecture standpoint, they do not love solar panels on the side of a building because there is no design flexibility. Cost is also an issue. There has to be a compelling financial return for the customer. Whether it is a homeowner or a building developer, the understanding is that there is a lot of cost pressure regarding exterior materials and since glazing is often at the very end, it is often devalued or engineered out. Builders and other stakeholders try to cut back to avoid going over budget and windows are often a target for these cuts. That said, the whole element around climate change and people embracing sustainability is very encouraging. People are executing and taking action on that. More developers and investors are committed to renewable energy. There has also been more discussion among trade organizations, builders, and others—this is influencing the industry mentality. A hurdle is that people are still really looking for a great solution that gives architects and builders more flexibility and design freedom.

In terms of specific use cases and good near-term targets for BIPV integration, it was noted that BIPV can be considered more of a premium product or technology. It is not really seen with standard types of homes and buildings. Those that are focused on just getting the building up in a timely or cost-effective fashion—those people are not interested. This company is seeing interest from the segments of the market that not only can afford it, but also embrace the non-financial value—being seen, being green, and supporting clean energy. Government owned buildings have embraced BIPV to an extent—often this is linked to mandates for renewable energy onsite. But for some buildings, this is not always practical or possible. Universities, healthcare organizations, and hospitals often have a more substantial budget and more money to implement new technologies—and these types of organizations are more likely to embrace a more sustainable building. Anyone in the net-zero energy space would be a good candidate for integration. However, they still have questions about whether that is a financially sustainable scenario. BIPV, in general, has not hit the mainstream because of some of the hurdles. Good near-term opportunities for BIPV would likely include government buildings, hospitals, healthcare, universities, and any new construction. He is not seeing as much BIPV with standard office buildings in office parks or standard residential developments. Apartment buildings can be an interesting exception. A real estate company or developer is interested in getting a good ROI on their building. In some cases, they are willing to invest in high-end technologies, if they feel like it will ultimately help with their ROI. Utility savings in a residential apartment building could trickle down to tenants, which can be attractive to some, and it might actually garner higher rent overall.

BIPV Glass Company

According to another company focusing on PV glass and glazing, there are a number of factors encouraging the adoption of BIPV in the residential and commercial segments. Solar, in general, is seeing great momentum—prices have continuously dropped and building regulations and state legislation have driven up the demand for solar, including BIPV. As building codes become more stringent with onsite renewable energy requirements, architects have realized that BIPV offers an opportunity to increase the amount of solar energy that they can produce out of the skin of the building, in an aesthetically pleasing manner. Product education is key for them to specify BIPV in their projects and being able to learn from existing installations helps quite a bit, too. A few years ago, there were not as many relevant BIPV installations available in the market for any customer to look at and learn from, but today there are many great references that can be useful to those interested in integrating BIPV into their projects.

Tax credits, MACRS depreciation, and other performance-based incentives have been and continue to be critical, especially because this is still somewhat of a niche market in the United States. These incentives do encourage many clients to move forward and pursue installation of BIPV products, both for new construction and renovation projects. The "Tesla factor" was once again noted as being an important driver of BIPV adoption. Their marketing has been effective and it has increased consumer knowledge of BIPV products. People are aware that more attractive solar technologies are available. It would be essential for the continuous growth of the industry to have more companies actively promoting BIPV across the country, so they can educate the market. This is a comprehensive process that involves educating glazing contractors, roof contractors, electrical contractors, designers, and consultants. It was noted that the European Commission has specific programs and funding for the development of BIPV as a critical material to renovate millions of inefficient buildings throughout Europe.

Major hurdles to adoption include a lack of product education (architects and other builders may not know about the technology or how it works) and product certifications can be difficult to overcome (UL1703 is the most important product certification for BIPV products). If entities interested in BIPV do not qualify for tax credits and incentives, they may lose interest in BIPV solutions because they do not want to incur higher upfront costs. This happens to a number of public buildings and projects with budget limitations, even though the ROI or payback could be very optimistic in the long run.

With respect to specific use cases and near-term targets for BIPV integration, airports, convention centers, shopping malls, transit stations, and museums have all been very active in the incorporation of BIPV products. Large multi-national corporations are also leading the effort, as they want to meet their ESG policies and become pioneers in sustainability and innovation. The commercial segment is the optimal segment for PV glass companies, since they can offer a more competitive price for large-scale projects. Both new construction and renovation projects are great for BIPV applications—about 40% of their projects are renovations.

Table 25: Summary of Feedback from BIPV Suppliers

Questions	Summary of Feedback and Key Takeaways
What factors seem to be encouraging the adoption of BIPV in the residential and commercial segments?	Four of the five BIPV companies spoke to Tesla's brand power and marketing, noting that this has generated a broader interest in BIPV that has been beneficial for everyone in the market. For solar, in general, prices are dropping and building regulations and state legislation have driven the demand for solar (including BIPV). Incentives like tax credits and MACRS (modified accelerated cost recovery system) depreciation continue to play a critical role—these incentives are effective in terms of encouraging people to pursue the installation of BIPV products, both for new construction and renovation projects. All of the companies mentioned improved aesthetics as a factor that seems to be encouraging BIPV adoption. There is also a desire for innovation, sustainability, and reduced energy costs. More developers and investors are committed to renewable energy. Factors such as increasing awareness and knowledge that BIPV products exist are also translating to an increase in use. More discussion among trade organizations, builders, and other stakeholders is happening and this is shifting the industry mentality.
What do you see as the major hurdles to adoption?	Four out of the five BIPV companies noted that cost is a considerable obstacle. Part of the increased cost comes from the complexity of the installation and the complexity of designing the product (each home and building is unique). Solar tariffs are also a problem for the industry, as these tariffs contribute to increasing product costs. If entities interested in BIPV are not eligible for tax credits or other incentives, they may not move forward with the BIPV installation. While BIPV elements do offer an improved aesthetic, some aesthetic issues persist. HOAs can be a problem, as they may be trying to keep solar out of "pristine" neighborhoods. Historic preservation projects may present a similar issue. While the look of the products is certainly an improvement over traditional solar panels, architects and builders are still seeking BIPV products that offer more flexibility and design freedom. There is a knowledge gap surrounding BIPV and this is an issue, as well. Many architects and builders are unfamiliar with BIPV elements, how they work, and how to integrate them. Even solar integrators will often talk down BIPV because they are not as familiar with the product. Contractor uptake and education is important if BIPV is going to see broader adoption.
Are you seeing increasing interest in BIPV in specific use cases or types of buildings? What are the most promising near-term targets for BIPV integration?	All three BIPV roofing companies discussed residential new construction as a segment seeing increasing uptake of BIPV elements (and specifically, BIPV roofing products and systems), particularly high-end homes (average, middle-income housing projects—not so much). Some commercial projects have been quoted, but often they do not move forward because of cost. The commercial utility rate is also generally lower than the residential rate, so a commercial installation is not as cost effective. In addition, you see more commercial buildings with flat roofs versus pitched roofs. Part

	of the value of BIPV—and especially BIPV roofing—is aesthetics. If you have a flat roof, the building owner would not benefit from the improved aesthetic. One company that is well established in the BIPV roofing segment is exploring BIPV elements and applications such as shade structures, rainscreens, siding, and residential carports. With respect to PV glass and windows, these companies are seeing interest from segments that can not only afford it, but also embrace the non-financial value—they want to be "green," support clean energy, and be recognized for being more progressive or eco-friendly. Government owned buildings have integrated BIPV, often this is linked to mandates for onsite renewable energy. Universities, healthcare organizations, hospitals, new construction, government buildings, apartment buildings, airports, convention centers, shopping malls, transit stations, and museums were all cited as good candidates for BIPV integration. The commercial segment is the optimal segment for PV glass companies because they can offer a more competitive price for large-scale projects.

4.4 FEEDBACK FROM ASSOCIATIONS

As part of this primary research effort, we reached out to a few associations focusing on the building industry. The National Association of Home Builders (NAHB) did respond with some comments.

The NAHB has, anecdotally, seen an increasing number of inquiries over the past year from builders about integrating rooftop solar PV into their offerings, but not as much regarding BIPV, specifically. Many of their Sustainability & Green Building subcommittee members make their homes solar PV-ready or incorporate rooftop solar if the customer wants it, and they usually do so through a solar installer partner (as opposed to installing the PV system themselves). That being said, they recognize that those subcommittee members comprise a very small percentage of the overall association. While they certainly know of some members that can incorporate rooftop solar, that knowledge is not necessarily widespread to an average builder member. Last year, the NAHB created a Solar Toolkit for Builders, designed to help builders who may have limited to no knowledge of solar PV get started in this space. The NAHB has recognized that there is significant untapped potential in the new construction space and they are a partner on a DOE-funded research project with the National Renewable Energy Laboratory (NREL) and a few other entities. Through this project (titled *Incorporating Solar Panels into the Ecosystem of Whole Home Re-roofing and New Construction Projects*), they will explore barriers to rooftop solar PV in new construction and re-roofing projects. Over the next few years, they will explore topics such as those that have been the focus of this report, but focusing on rooftop solar, more generally.

4.5 PUBLISHED COMMENTARY FROM EXPERTS IN THE BIPV MARKET

In addition to the primary research findings a number of individuals with expertise in the BIPV market have discussed trends, market dynamics, challenges, and other factors that may provide insight as to why the industry has not yet witnessed widespread BIPV adoption.

According to Martin DeBono, President at GAF Energy (this $3 billion company sells a solar tile product called DecoTech), mandates for solar—such as the mandate in California—has prompted leading roofers in the region (such as Citadel and PetersenDean) to partner with solar companies such as Sunnova, Sunrun, and SunPower. These partnerships are thought to be a foreshadowing of next-gen BIPV. While most contractors still rely on traditional solar PV panels, some industry experts (DeBono included) believe that "roofing and solar will become increasingly intertwined."[186]

Dr. Lance Wheeler, a researcher at the National Renewable Energy Laboratory (NREL), has noted that the building and solar industries are "heavily siloed," and this is one key hurdle to BIPV adoption. NREL has previously focused on pricing and bringing down the cost of solar to encourage adoption. The technology has met cost and performance goals, so now the organization is exploring applications for PV and BIPV, including the use of BIPV on vertical surfaces.[187] He has indicated that there may be an "opportunity for solar to be deployed where builders currently install opaque spandrel glass, which is used on glass buildings to cover the exterior areas between floors."[188] The BIPV applications that are completely integrated into the building's design may take more than a decade to gain that kind of widespread acceptance; however, shorter term opportunities may be there for PV windows and vertical façade applications. Many industry experts seem to agree that solar companies and builders need to work collaboratively if BIPV is going to see more widespread adoption.

According to Ravi Manghani, Wood Mackenzie's Head of Solar Research, BIPV may not succeed in the market based purely on economics. He believes that there are niche applications where BIPV will meet a need that traditional solar modules cannot address. For example—buildings in urban environments or areas with land-use restrictions. However, "none of these limits are going to be significant [enough] for BIPV commercialization, not in the next decade."[189]

The BIPV market and the key players within the market should also be considered. There are a number of BIPV companies that have failed—but many of them, including Konarka and Xunlight, were startup companies. There were also large companies, such as BP and Dow Chemical, that made attempts to develop solar shingles—but both companies decided to discontinue production. It is believed that the strong financial position of companies such as Standard Industries, the parent company of GAF and GAF Energy, will help BIPV to navigate over hurdles to commercialization. Tesla is another major player in the BIPV market and their brand appeal is powerful. Tesla has a loyal customer base whose interest in solar may kickstart BIPV market growth and adoption. If early adopters are willing to jump into a new technology and take a risk, it will start to gain some visibility and ultimately this increase in adoption will bring the cost down.[190]

In the current climate, builders are skeptical of BIPV. As a result, solar companies are working to integrate with roofers. Within the next decade, industry experts expect that roofing and building material providers “will have swallowed standalone solar companies.”[191] However—before that happens—there will be a need for more universal training and permitting. Installing solar products can also mean wires on traditionally analog materials, which would also lead to some changes in the way things are done. The building industry is somewhat conservative and there are limits in terms of how much they are willing to invest to adopt new technologies and tools, and re-train their labor force.[192]

5.0 Key Stakeholders & Their Role in BIPV Adoption

Image Source: Neepster (2005). [FlickR](). .

5.0 KEY STAKEHOLDERS AND THEIR ROLE IN BIPV ADOPTION

This section discusses the various stakeholder groups and their role in supporting the commercialization and adoption of BIPV.

5.1 INTRODUCTION TO BIPV STAKEHOLDERS

As referenced earlier in this report, the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and Becquerel Institute released a report in 2020 titled *Building Integrated Photovoltaics: A Practical Handbook for Solar Buildings' Stakeholders*. Despite the fact that BIPV systems have been available for a number of years, architects, installers, and experts within the building and construction industry often do not have the knowledge and expertise to evaluate the costs necessary to implement a BIPV system. This uncertainty among architects, builders, and other stakeholders can lead to an increase in construction costs—which are largely "due to misperceived risk and a wrong timing evaluation."[193] The following figure, developed by Becquerel Institute, maps BIPV stakeholders and depicts the relationship that exists between the owner of the BIPV system and each stakeholder group.

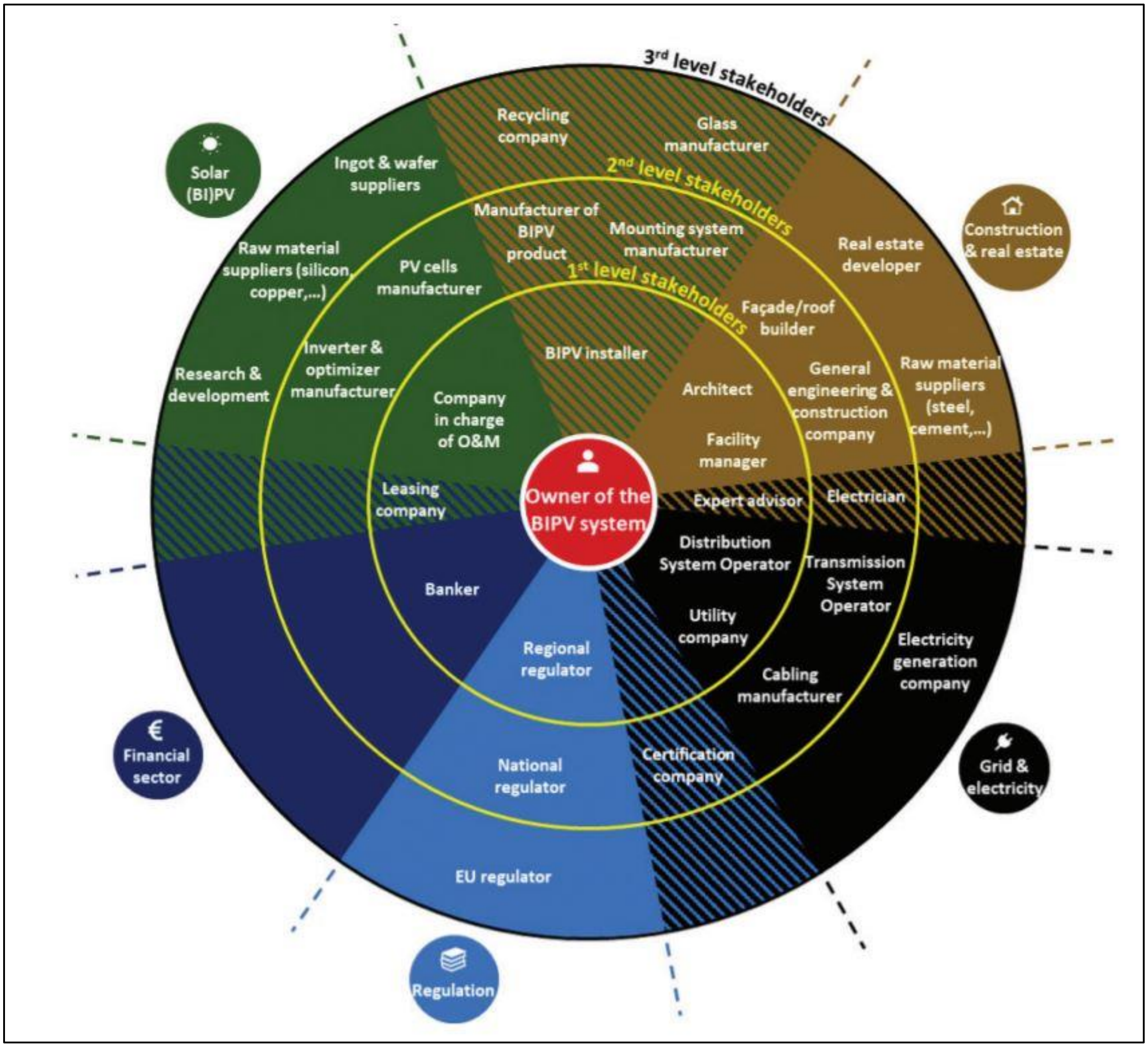


Figure 12: BIPV Stakeholder Map (Becquerel Institute)[194]

A 2021 report from BCC Research included the following figure, which was sourced from Becquerel Institute (BIPV Boost). The figure outlines the various BIPV project development steps and highlights the main stakeholders associated with each step. The stakeholders with early involvement and influence in the process include investors and those financing a project, as well as architects and companies with dual expertise in PV and construction.[195]

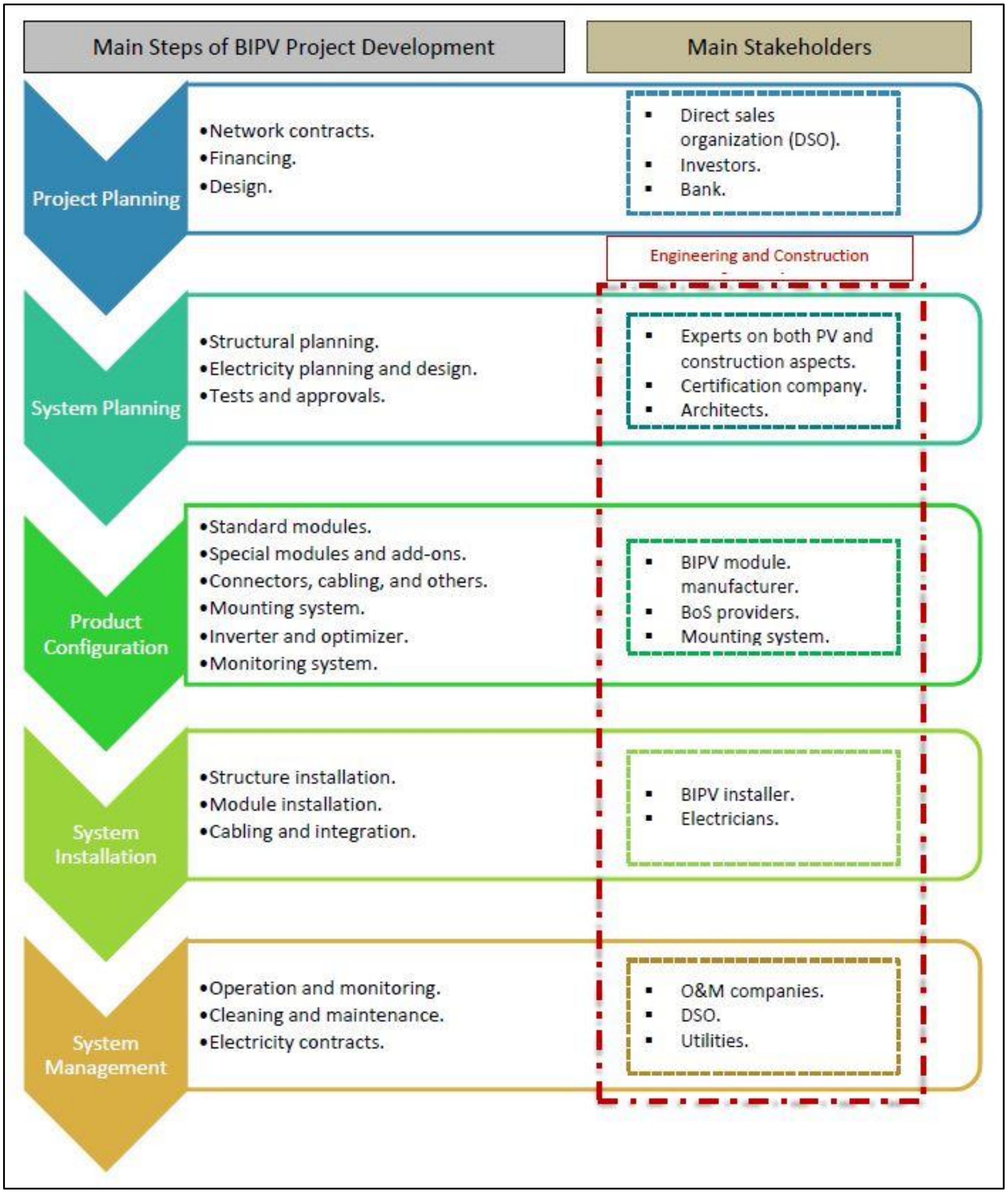


Figure 13: BIPV Project Development Process (Becquerel Institute via BCC Research)[196]

Stakeholders within the BIPV ecosystem can be characterized by their "degree of influence" on BIPV projects. There are primary stakeholders (those that have a medium to strong influence on BIPV project development) and secondary stakeholders (those that have little to no influence on BIPV project development).[197] Generally speaking, architects, general construction companies, facility managers, policy makers, building owners, project investors, and BIPV manufacturers are regarded as primary stakeholders. Architects can decide if BIPV is going to be integrated into a project's design and they also determine how BIPV will be integrated. Project investors are also quite influential, as they are responsible for the capital funding the project. Policymakers tend to have a high influence on the value chain and ecosystem, but their interest level is more moderate. They can develop and implement regulations, which can increase pressure or motivation to implement BIPV or other types of renewable energy technologies. Policymakers also have the power to enact financial incentive programs, which can certainly make BIPV more attractive.[198]

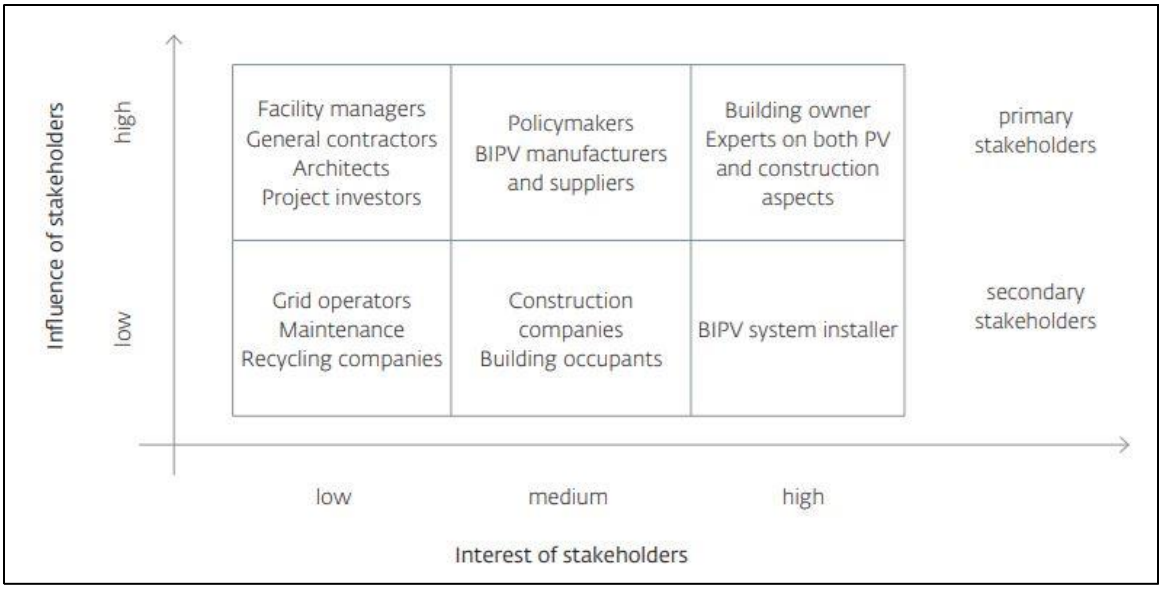


Figure 14: Categorization of BIPV Stakeholders in Terms of Influence and Interest (SUPSI and Becquerel Institute)[199]

Different groups are faced with different and sometimes unique challenges. Many stakeholder groups will be impacted by the complexity, aesthetic, and cost challenges that are specific to BIPV. General contractors are likely to face an increase in cost, and cost can also discourage building owners and investors from pursuing BIPV. Architects are impacted by new constraints imposed by BIPV—such as constraints related to design, technical characteristics, and structural characteristics. Architects may need additional training, knowledge, and the development of new skills before they feel confident implementing BIPV technology. Professionals who have expertise in both PV and building could meet a need, as they could provide this expertise to architects and help them gradually learn more about BIPV and what it takes to successfully and cost-effectively integrate this technology into their building designs. While it can be challenging to find a person who fits this profile (an expert in both building and construction, as well as PV), their role is crucial for encouraging adoption in the building and construction industry. These experts can help stakeholders to "optimally integrate BIPV in the project design and planning phase, by offering support to architects and construction companies, thus facilitating the project and reducing costs."[200] This role could be potentially addressed by BIPV installers who may have expertise in both building and solar PV.

Implementing innovative technology into the construction and building industry can lead to knowledge and process gaps. Architects would need to focus more on green design and energy efficient design. Investors and building owners may be hesitant to pursue BIPV integration due to the additional investment that might be required or because they are simply lacking a thorough understanding of the technology and how it will impact the project. Training, education, and effective communication across all sectors—from the start of project planning—are essential elements for successful BIPV integration.[201] Experts on both PV and building, as well as BIPV installers, can provide education and expertise. In addition, the use of digital tools like simulation and BIM-based software can also be quite helpful.[202]

To achieve broader acceptance of BIPV, buy-in from final users and architects will be required. From the perspective of a final user, a BIPV product should be aesthetically pleasing, it should not compromise the operation of the building skin, and any BIPV solutions must be cost-effective. BIPV can increase the value of a building or home, and it can convey an eco-friendly and/or high-tech image. From the perspective of an architect, an acceptable BIPV system or product will need to combine a high degree of flexibility in terms of module dimensions, colors, distribution of the PV cells, and offer high energy production capability. Cost effectiveness is also important. BIPV cladding is expected to be comparable to traditional materials in terms of flexibility, safety, and reliability.[203]

5.2 ARCHITECTS AND DESIGNERS

Architects and designers play an important role, in terms of BIPV adoption. Generally speaking, they represent a first-level stakeholder and have a high degree of influence as to whether or not BIPV elements are incorporated into the design and how they are incorporated into the building. However, they do not have a financial motivation for incorporating BIPV technology, so interest is often low. According to a June 2020 report from the International Energy Agency's Photovoltaic Power Systems Programme, architects have a very high degree of influence on the decision-making process and they would largely be responsible for choosing a BIPV system. The architect is in direct contact with the building owner and they will have significant influence over the final decision. The interest of architects is generally low if they have no experience with BIPV or if they have other ideas for the design of the building. Many architects see BIPV as an additional constraint to creativity.[204]

Architects may lack the knowledge and expertise to effectively evaluate the costs of implementing a BIPV system. In addition, this group may be impacted by the constraints imposed by BIPV, notably constraints related to design, technical characteristics, and structural characteristics.[205]

A 2019 article discussed Helmholtz-Zentrum Berlin (HZB), a German research center that performed a needs analysis by engaging with stakeholders from all fields of BIPV in 2018.

The effort attempted to explore why BIPV continue to play a marginal role in the solar industry, and why they are so rarely used in new construction projects. The technology itself seems to be sufficient, in terms of performance. However, many of those in the construction industry (those performing both new-build and/or renovation projects) have stated that the majority or architects, planners, and builders/owners “simply do not have sufficient information about the technical and creative possibilities for the integration of PV into their projects.”[206] These stakeholders—including architects—have reservations about BIPV, including unappealing designs, high costs, and a level of complexity that can be viewed as prohibitive.[207] Architects may require additional training, knowledge, and the development of new skills before they truly feel confident implementing BIPV technology. It is important to overcome any misconceptions by developing a better understanding of architect and builder needs and how these groups are perceiving BIPV.[208]

A paper titled “Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths” was published in the journal *Green* in 2013. This paper describes the roles of key stakeholders in the BIPV segment—namely manufacturers, planners, and architects. According to the paper, integrating BIPV can add complexity to the planning process, requiring knowledge and expertise that the architect and home or building owner may or may not have. As the BIPV market is emerging and some companies will enter the market only to leave it (as has been the case with a few startup companies), the market can come across to stakeholders as being a bit confusing and potentially unstable. Architects and project planners have largely been the groups that have had to act as a champion for BIPV, if BIPV is going to be integrated into the construction of a new building or home. This is often met with resistance from investors, who oppose the rise in building costs and aim to do what is most cost-effective. While architects would represent a key stakeholder, in terms of driving BIPV adoption, the problem of aesthetics persists. If PV causes aesthetic issues, this can complicate the planning process and limit the creativity of the architect.[209] With that said, with the trend toward zero energy buildings and energy-efficient buildings, as well as the development of more attractive and customizable BIPV options, architects may be increasingly willing to consider BIPV integration if it falls within budgetary constraints.

Ultimately, buy-in and acceptance from architects will be required if BIPV is to achieve widespread and mainstream adoption. From the perspective of an architect, acceptable BIPV elements or products will need to combine a high degree of flexibility in terms of module dimensions, colors, distribution of the PV cells, and they will need to offer high energy production capability.[210] Architects and builders expect that building envelope materials will fulfill conventional functions—BIPV or the generation of electricity would be an additional property or benefit. Developers of multifunctional BIPV technologies and materials would likely benefit from focusing on the development of BIPV elements that are more customizable and aesthetically pleasing (as well as cost-effective), standards (which may be part of planning tools, such as BIM), technologies with a high resilience against temporary shading, and technologies with long-term stability in terms of both power output and also durability and appearance. The development of concepts for monitoring and maintenance (keeping in mind factors that are specific to the building site or installation), as well as product compliance with legal requirements, codes, and standards are also important factors for consideration.[211]

Architects with a focus on green or energy-efficient design could be a key group to champion BIPV. Building "green" (which could include BIPV, among other technologies and elements) can be profitable for architects, in terms of attracting clients and building a reputation. [212]

The Architectural Solar Association is an industry association established to support the developing trend of architectural solar. An article from the Architectural Solar Association, featuring Jeff Horowitz, Director of Business Development and Partnerships at NEXT Energy Technologies (a PV window technology specialist), noted that the "need to save energy in buildings is becoming too big for developers and architects to ignore."[213] Energy is the top variable operating expense in commercial buildings and buildings collectively consume about 40% of global energy—they are a significant part of the problem. The promotion of net-zero energy buildings is also supporting the architectural solar segment. Horowitz notes that adding a few solar panels to the roof of a large commercial building is not going to make a building net-zero. He believes there is a growing gap in the market for the integration of PV into building facades and windows, particularly those on large commercial buildings or buildings situated in complex landscapes (dense urban areas).[214]

While architectural solar is a growing segment and this trend seems to be accelerating, it is important to note that architectural solar continues to be quite complex and it requires the cooperation among many stakeholders—including building owners, architects, construction companies, glaziers, building envelope suppliers, and civil electrical contractors. Many of these stakeholders have a limited appreciation for renewable energy, but they do understand glass, facades, building materials, and roofing. If BIPV product suppliers talk to these stakeholders about a building material (glass, roofing tile, etc.) that integrates technology, this may spark their interest. Approaching BIPV from a building materials standpoint, rather than an energy production standpoint, could potentially generate more interest. Pitching BIPV as a new building material, not necessarily as a source of energy, could encourage companies to reconsider BIPV.[215]

5.3 GENERAL CONTRACTORS, BUILDERS, AND BUILDING OWNERS

General contractors and builders represent another key stakeholder group. As with architects, this group may lack the knowledge and expertise to properly evaluate the costs of implementing BIPV and they may worry about this uncertainty and inexperience translating to issues with the project down the line (leading to an increase in construction costs). Builders, like architects, have a high level of influence when it comes to BIPV integration and they are regarded as a primary stakeholder. General contractors are likely to face an increase in cost if BIPV elements are added to a building and this cost increase can discourage those builders—as well as building owners and investors—from pursuing BIPV.[216] Just as with architects, builders have a few reservations about BIPV, including unappealing design, high costs, and complexity. Those motivated to accelerate BIPV adoption will want to overcome these misconceptions by establishing a clear dialog with architects and builders, understanding their needs and how these groups are perceiving BIPV.[217]

Builders may be the building owner (in the case of a developer, for example) or they may work closely with the building owner. It would be difficult to realize a BIPV project without a sound business model, from the perspective of the builder and/or building owner. These stakeholders will need to be convinced that a BIPV system is the ideal solution for their building when considering financial, public relations, and environmental factors.[218] General contractors may look more favorably on BIPV if there are internal policies allowing for a higher level of risk and higher RoI periods. Building owners may stand to benefit from reductions in energy bills, an enhanced public image, increased property value, and a tax reduction or other financial incentives.[219]

In a 2018 paper by Hans Christoph Curtius, titled "The Adoption of Building-Integrated Photovoltaics: Barriers and Facilitators," he explores the issue of low BIPV adoption, despite clear benefits of the technology. He conducted over 40 interviews with stakeholders across the BIPV value chain, exploring barriers and facilitators to adoption. Curtius notes that "successful BIPV policies should create clear incentives for BIPV adopters, either in the form of financial support or inclusion of BIPV in building codes or labels."[220] With respect to marketing, it is recommended that BIPV suppliers develop targeted communication strategies directed at building owners and architects. Offering solutions such as turn-key solar roofs was also suggested, as these solutions would help to overcome concerns regarding the complexity of BIPV.[221]

5.4 INVESTORS

Investors and those funding building projects represent another key group, in terms of BIPV adoption. They can be quite influential because they are responsible for the capital funding for the project. According to a report from the IEA, banks and leasing companies tend to have a low level of interest in the BIPV market. These stakeholders are most concerned with the economic model built around the BIPV project. If the end-result looks good and the owner is in a good financial position, banks and leasing companies will typically finance the project. Their influence is important because they could "threaten the feasibility or attractiveness of [a] project by refusing to finance it or requiring high interest rates."[222] In general, BIPV integration is met with resistance from investors, who oppose the rise in building costs and aim to do what is most cost-effective.[223]

To gain buy-in from investors, the industry may have to shift the general line of thinking. Currently, it is often the case that the implementation of renewables will be disregarded—this is thought of as an add-on or enhancement to the building. Moving forward, it would be helpful if the standard practice involved calculating building costs with BIPV included. Ideally, it would become standard to attract buyers by calculating the advantage of low energy operating costs and promoting this as an asset.[224] These trends may need to be realized before the industry sees greater support from investors and those backing major construction projects.

5.5 CONSULTANTS

With respect to the more complex applications of BIPV, it has been suggested that BIPV consultancies (consultants with a dual expertise in construction and BIPV or solar PV) could play a very important role. Consultancies specializing in BIPV integration could offer stakeholders (such as architects and builders) accurate knowledge of the market and information about BIPV products best-suited for a specific building or project. This would help to eliminate some of the confusion surrounding BIPV integration and the uncertainty that might come with adopting innovative technology and building materials. While some construction companies may not fully embrace the concept of a BIPV consultant or BIPV service manager, having a person or consultancy with this expertise could be helpful for technology adoption. This entity would essentially bring together the PV industry and BIPV providers, the construction industry, property owners, project developers, architects, and craftsmen to integrate BIPV into the planning process from the very start of the project.[225] A number of sources have discussed the importance of integrating PV into a project in the early planning stages, as this optimizes performance and aesthetics.

Professionals who have expertise in both PV and building could meet a need, as they could provide this expertise to architects and help them gradually learn more about BIPV and what it takes to successfully and cost-effectively integrate this technology into their building designs. While it can be challenging to find a person who fits this profile (an expert in both building and construction, as well as PV), their role is crucial for encouraging adoption in the building and construction industry. These experts can help stakeholders to "optimally integrate BIPV in the project design and planning phase, by offering support to architects and construction companies, thus facilitating the project and reducing costs."[226] This role could be potentially addressed by BIPV installers who may have expertise in both building and solar PV.

Helmholtz-Zentrum Berlin (HZB), a German research center, has led a novel initiative to promote BIPV adoption, founding a Consultancy Office for Building-Integrated Photovoltaics (called BAIP). BAIP focuses on key decision-makers for construction and renovation projects and the unique needs of these decision-makers. The team is comprised of those with extensive PV experience, as well as architects specializing in this area. BAIP offers free consulting services for architects, planners and building owners. Their focus is on providing information about BIPV and addressing potential obstacles, with the goal of getting these key stakeholders to start considering—and eventually integrating—BIPV into their building and construction projects.[227]

5.6 SUMMARY

There are a number of stakeholder groups that will collectively influence the adoption of BIPV. However, those with a high degree of influence include architects, building owners (which can include developers and builders), and project investors. Architects, particularly those focusing on green or energy efficient design, may act as a champion for BIPV integration. The establishment of the Architectural Solar Association is promising, as this suggests that there is an increasing industry focus on architectural solar. This association could play a significant role, in terms of addressing the hurdles to BIPV adoption relative to the architect stakeholder segment. The establishment of consultancies that jointly specialize in building construction and BIPV would also be a key factor in overcoming some of the significant challenges that persist. These consultants would support architects and builders, increasing confidence and knowledge with respect to BIPV elements and how to properly integrate those elements.

In the primary research conducted with architects, designers, EPC firms, and prefab home builders, certain themes came up recurringly. Cost continues to be an issue. Part of the cost issue may be due to perception or assumptions. The idea is circulating that BIPV is expensive, but there are some that have not necessarily priced it out. A detailed cost/benefit analysis could be very helpful. Installation is also a consideration. Due to installation sequencing, it does not make sense most of the time to integrate roofing, as roofing is completed onsite. Some were hesitant to have PV integrated into the actual building materials. Adding the PV function seems like one more thing that can go wrong—and if it does, they may have to replace part of the actual building, as opposed to just part of the standard PV array. While integrated solar roofing products and systems generally offer improved aesthetics, in many cases, PV panels offer more wattage per square foot (and they are less expensive).

Any BIPV elements should easily integrate with other systems already on the market and it should be easy to attach them to existing window and door frames (this is particularly important for PV sun shading elements, in particular). A few people noted that they would love to see more product offerings, particularly as window shading elements and solar canopies. Roofing was discussed frequently, but it was mentioned that roof space is a commodity right now. There has been increasing interest in occupiable roofs and green roofs, so canopies and other shading elements might be well received. Buildings could still integrate solar, but the roof would be available for vegetation or occupiable spaces.

The knowledge gap was noted as a considerable obstacle. A lot of people do not necessarily understand BIPV (what it means, what it looks like, how to assemble and install it, etc.). All stakeholders need to be educated on BIPV elements. Architects, in particular, may benefit from consultancies that specialize in both solar and BIPV, as well as the building and architectural industry (or more resources that bring these two industries together). This would help to bridge the knowledge gap and support architects as they learn how to integrate BIPV into their projects.

6.0 Builders, Roofers & Installers

6.0 BUILDERS, ROOFERS & SOLAR INSTALLERS

BIPV is an emerging market that has yet to achieve widespread commercial adoption; however, solar PV installations are becoming more common. Understanding the dynamic that exists among builders and solar installers, as well as roofers and solar installers, may provide some insight as to how key stakeholders—such as builders and roofers—may work with BIPV companies and installers moving forward. This section begins with a general discussion of builders and solar installers before summarizing factors that are both hindering collaboration and encouraging collaboration. This is then followed by a similar discussion of roofing companies and solar installers, once again focusing on factors that are hindering and encouraging collaboration among these groups.

6.1 BUILDERS & SOLAR INSTALLERS

There are a number of factors influencing the degree of collaboration among roofing companies, builders, and solar PV installation companies. One could begin this discussion with a focus on builders.

When building a home, builders are able to present potential buyers with a number of exterior options—they have an opportunity to include solar PV technologies or building integrated photovoltaic (BIPV) materials as an option.[228] Common reasons cited for not adding solar PV on a new home or building include financial reasons, lack of customer desire, and in some cases limited availability of qualified solar installers in the area.[229]

With states like California (and perhaps Massachusetts) shifting to mandates requiring residential and/or commercial solar, this will have an impact on a number of stakeholders, including homebuilders and roofing contractors. Builders are going to have a few options for implementing solar. They can contract with solar dealers or have solar dealers bid on individual projects, have homeowners pay for the solar technology upfront, or builders can create in-house solar teams to perform the solar installation. States like California require a solar energy contractor's license for solar panel installation. State and local requirements for training and certification will likely come into play, as this avenue would be an investment in time (and perhaps money) for the builders to become certified to install solar PV.[230]

If a homebuilder wants to install solar panels, they have to be certified to do so. The North American Board of Certified Energy Practitioners offers programs and certification to ensure that professionals are able to safely install, operate, and maintain the solar panels. Construction companies and builders who want to expand their service offerings to include solar panel installation must be sure that they have the proper training and certification to do so. Training can vary from state to state and local laws and regulations may also be applicable.[231]

The National Association of Home Builders (NAHB) has provided guidance related to builder and solar PV installer partnerships. Builders may choose to pursue the path to certification, enabling them to install their own solar PV panels; however, this may require companies to hire additional employees with solar expertise. If that is something that a builder does not want to pursue, they may benefit from partnering with an established solar PV installer. These relationships can be beneficial for both parties. The builder can work closely with a solar installer to better understand their designs and have the solar installer's work customized so that it is ideal for each of the homes being built. Solar installers clearly benefit in that they receive repeat business from builders.[232]

Efficiency is certainly one factor that can bring builders and solar installers together early in the process. A solar PV installer that gets involved during the design phase of a project will be able to analyze the site and determine if solar is a viable option for the project. The solar installation company can work with the builder's design team and architect to make any changes which would be needed to accommodate solar panels or BIPV. Getting on the same page early in the process will eliminate unnecessary labor costs for re-design, it will ensure that the house is optimally oriented for solar energy capture, and it will facilitate proper roof load design (this would avoid the need for any unanticipated structural supports or added costs later in the project). Collaborating early can be beneficial in that builders and architects can account for solar in the design phase—potentially moving or eliminating potential shading obstructions that may be typical on a roof without solar panels (like chimneys, vent pipes, and skylights).[233] Solar installers will likely have expertise in local utility regulations, rebates, and they will have established relationships with local equipment distributors—all factors that will help builders navigate this growing market.[234]

In January 2018, the National Renewable Energy Laboratory released a report titled *Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030*. The report was funded by the U.S. Department of Energy's (DOE) Solar Energy Technologies Office and, as part of the report, authors interviewed a number of individuals and organizations to better understand the residential solar PV landscape. According to the report, "between 2017 and 2030, an average of 3.3 million homes per year will be built or require roof replacement."[235] There seems to be opportunity to integrate solar into newly constructed homes and buildings, as well as existing homes requiring roof replacements.

According to the report, it is envisioned that a low-cost integrated PV and roofing product will be available by 2030—this would reduce supply chain, installation labor, and permitting costs because the PV and roofing materials would be shipped, installed, and permitted simultaneously.[236] Continued innovation is required to develop such low-cost integrated PV products. Currently, these customized products (integrated PV and roofing products, like solar shingles and other BIPV technologies) are produced on a smaller scale, they require manufacturing process changes, and they also require more skill and time to install. Collectively, these factors translate to added cost. In addition, current BIPV technologies (like solar shingles) have lower efficiency compared to conventional PV modules, which makes them more expensive.[237]

The report addresses business model integration. Integrating business models can provide cost savings in areas such as sales and marketing, overhead, labor, and PII (permitting, inspection, and interconnection). With that said, there are challenges to consider for PV installed at the time of roof replacement and PV installed at the time of new home construction.

Solar companies may work collaboratively with homebuilders (or commercial builders) to install PV on new housing developments and buildings. In the case of getting PV on newly constructed homes, the homebuilder would be the targeted customer for solar companies. Homebuilders will often retain the same solar contractor across multiple developments, which can result in sales and marketing savings. Currently, most homebuilders do not incorporate PV into all new housing developments. However, an increase in consumer interest could change this. As homebuyers become more familiar with the benefits of solar PV, market demand for PV on new construction will increase. However, it has been noted that the impact of this may be limited because PV might compete with other home upgrades which would provide higher revenue to the homebuilders. Favorable policy (such as that enacted in California) may increase demand for PV and collaboration among solar companies and homebuilders; however, this is not enough on its own. When builders in California incorporate PV into new construction (as a Title 24 compliance measure), the PV can be included in the master building permit. However, there are PII issues with this approach—delays in PV PII can delay the entire construction project. Changes made to the PV system after the master building permit has been submitted would also result in delays and inefficiencies. Allowing “more flexibility for PV systems in the master building permit could address these concerns.”[238] Many solar partners are also left out of the design phase of housing developments, an obstacle that prevents the solar and new construction industries from fully benefiting from collaboration. When a PV installer is left out of the planning process, “it has limited ability to co-optimize system design and roof layout, or take advantage of streamline wiring and conduit with PV-ready housing designs.”[239]

In the new construction segment, PV engineers design and size systems without having access to homeowner electricity use data. This can result in standard system designs that are smaller than those that might be installed for a residential retrofit. The development and widespread use of software to more effectively model plug loads could help engineers to more effectively size these systems.[240]

6.2 BUILDERS & SOLAR INSTALLERS: FACTORS HINDERING COLLABORATION

There are a few noted obstacles that are preventing builders from partnering more frequently with solar PV companies. While the cost of solar PV systems is decreasing, costs are still considered to be relatively high for BIPV and technologies such as solar shingles—the cost of such systems may correlate with a lack of customer interest, which may translate to a lack of builder interest. In addition, a lack of consumer awareness may play a role. Currently, most homebuilders do not incorporate PV into all new housing developments. However, increasing consumer interest could lead to greater implementation of solar PV into new build homes and buildings. As homebuyers and building owners become more familiar with the benefits of solar PV, market demand for PV on new construction may increase. Even still, the impact could be limited because PV may compete with other home upgrades that would generate higher revenue for the builders.

In some areas of the country, there may be a limited number of qualified solar installers, which could hinder the formation of partnerships among builders and solar PV installers. In some cases, builders are motivated to become certified to install solar PV themselves, bypassing strategic partnerships with established solar PV installers. However, there are challenges with this approach—it is a financial investment, it takes time for a company to become properly trained and certified, and they may have to hire additional employees with solar expertise. Certification is not always straightforward; it can vary by state, and local laws and regulations may add an additional layer of complexity.

The addition of solar PV can also increase project complexity and cause issues related to permitting, inspection, and interconnection (PII). For example, in California builders incorporating PV into a new construction project can include PV in the master building permit; however, delays in PV permitting, inspection, and interconnection can delay the entire construction project. Changes made to the PV system after the submission of the master building permit can also result in delays and inefficiencies.

Many solar partners are left out of the design phase of housing developments and the initial design phases of construction projects, more generally. This represents an obstacle preventing solar companies and builders from fully realizing their potential for collaboration. When a PV installer is left out of the planning process, they end up with a limited ability to co-optimize system design, roof layout, and streamline wiring and conduit with PV-friendly housing designs.

6.3 BUILDERS & SOLAR INSTALLERS: FACTORS ENCOURAGING COLLABORATION

While there are some obstacles and limitations hindering the collaboration of builders and solar installers, there are also a number of factors encouraging collaboration among these key stakeholder groups. Mandates are playing a role in encouraging collaboration—particularly in states like California, where a solar energy contractor's license is required for solar panel installation.

While some builders feel it is worth the time and investment of becoming certified to install solar PV panels or BIPV directly, many choose to instead work closely with a solar installer. Having a strategic partnership with a solar installer can be beneficial for builders in that they are able to work closely with the solar installer to better understand their designs and have the solar installer's work customized so it is ideally suited to each of the homes being built.

When builders and solar installers collaborate and form a relationship early in the building design process, this can lead to efficiency improvements in implementing PV. A solar PV installer that becomes involved during the design phase of a project will be able to analyze the site and determine if solar is a viable option for the project. The solar installation company can work with the builder's design team and architect to make any changes that are necessary to accommodate solar panels or BIPV. Collaborating early in the process will eliminate unnecessary labor costs for re-design and ensure that a house or building is optimally oriented for solar energy capture. It will also facilitate proper roof load design, which would avoid having to add any unanticipated structural supports or added costs later in the project. Early involvement of solar PV installers can be beneficial in that builders and architects can account for solar in the design phase, moving or eliminating any potential shading obstructions that might be seen on a typical (non-solar) roof (i.e., chimneys, vent pipes, and skylights). Solar installers typically have expertise in local utility regulations, rebates, and they will have established relationships with local equipment distributors. These factors can help builders navigate the solar PV market space, which may be less familiar to them.

According to the analysis by NREL, when homebuilders work with a solar PV installer, they often retain the same solar contractor across multiple developments, resulting in sales and marketing savings.[241]

6.4 ROOFERS & SOLAR INSTALLERS

In addition to builders, roofing companies may also develop strategic partnerships with solar PV installers. There is discussion regarding the dynamic that exists between roofers and solar PV companies. In many cases, roofers do have strategic partnerships or relationships with solar PV installers in their area. However, a trend that seems to be garnering some momentum pertains to roofing companies adopting solar PV installation as one of their services—or the opposite, solar PV installers becoming roofing companies. The industry is seeing a gradual shift from two industries that have historically operated in parallel (roofing and solar PV) to an intertwined segment featuring an increasing number of companies opting to provide both services.

Whether a roofing company decides to form a strategic partnership with a solar PV installer or whether a roofing company decides to actually become the solar PV installer (the roofing company would need to obtain a license to install solar panels), there will be benefits and challenges associated with each arrangement. When roofing and solar PV installation services are provided by a single company, this streamlines the job of the general contractor, who now only has to hire one company (to perform both roof and solar installation).[242] From an installer's perspective, being able to sell two products instead of one will improve their revenue generation and enable cost efficiencies which they can use to further improve profitability. This may also benefit the builder or homeowner, as it may result in some savings for them, as well.[243] Homebuilders are starting to establish relationships with companies (manufacturers and installers) that provide both roofing and solar solutions. This model is viewed by many builders as being beneficial, in the sense that it leverages efficiencies related to both cost and labor, and streamlines the process for the builder.[244]

When roofing companies are also responsible for installing the solar panels, there is a "reduction in defect claims from solar installations after the roof is installed."[245] According to one source, the average home has 14 points of penetration. This could include bathroom vents, kitchen hood vents, and other typical penetrations on the roof of an average home. An average solar system has between 25 and 50 penetrations, increasing the likeliness of leakage if installation and flashing is not performed perfectly.[246] Roofers may feel better about doing the solar installation themselves to ensure adequate work, thorough inspection, a single contract, and one warranty, among other factors. Tax incentives may also defray part of the cost of installing the solar panels, which could be attractive to roofers looking to add solar PV installation to their list of services.[247]

According to an article from *Solar Power World*, U.S. residential solar installations are growing and now is a good time for roofing companies to diversify their business and explore the option of expanding their services to include solar PV installation. There are a few reasons why it makes sense to combine roofing and solar—either through a strategic partnership (roofing company and solar installer) or one company providing both services. Approximately 75% of roofs in the United States are made of asphalt shingles and the average lifespan for this type of roof is 15-20 years. Depending on the age of the roof, a roof may need to be completely re-done before adding solar panels. The average lifespan of a residential PV system is about 20-30 years, which means that an average asphalt roof is likely to need replacement before the end of the PV system lifetime. In addition, about 20% of residential solar jobs are not completed by the solar PV installer because the home needs a new roof at the time of the installation.[248] It is easy to see how the roofing and solar PV segments are synergistic.

There are also risks and challenges to consider with this model (roofers becoming solar PV installers). These risks may include increased costs associated with compliance, as well as increased liability. Homeowners often file claims against solar installers for failing to meet performance standards—these claims would fall on roofing companies that are also installing solar panels. Roofers would need to address this issue in their contracts if they decided to install solar panels.[249]

Some solar installation companies are also electing to add roofing to their list of services. When customers needed a new roof prior to installing solar panels, the hired roofers often had schedules that were inconsistent with the solar company's schedule and this negatively impacted the installation timeframe preferred by the solar installation company. In addition, many roofers would automatically void a new roof's warranty after the solar company made penetrations to the roof. Some solar installers are turning to roofing to provide a more streamlined experience for customers, prevent a backlog of solar projects, and bundle warranties. According to one company that now does both solar installation and roofing, there was "a lot of finger pointing going on when roofs leak."[250] The company has found that by providing both services, they can ensure a quality job and include the roof and solar into linked warranties.[251]

Roofing companies can become certified solar PV installers (and vice versa)—this path can be quite profitable for companies that are then able to provide both roofing and solar PV installation services; however, some effort and investment is required to obtain the additional certification. Partnerships involving roofing companies and solar installers can be beneficial, as well. Roofing companies can ask homeowners if they have ever considered solar and, if interest is there, they can sell that lead to a solar installer. In another vein, roofing companies can complete a more thorough qualification process to ensure that solar is a viable option for the home or building owner, and then sell that qualified lead to a solar installer. This qualified lead could include information such as qualification for the solar federal tax credit, their motivation for going with solar, the name of their electric utility and usage information, and the age of their roof. Roofers can also partner with solar installers in such a way that the roofing company would actually sell the PV system to the home or building owner, but work with a third-party solar company to install the PV system.[252] These partnerships may also benefit roofing companies, in that solar installers may bring leads to the roofers.[253]

However, there are some issues to consider when roofing companies do not install the solar panels, themselves. Roofing companies need to be both aware and protected (contractually) if they are not installing the solar panels on a newly constructed home, as the solar installer will be coming in shortly thereafter to perform their part of the job. In 2016, it was reported that "40% of new solar installations on existing roofs resulted in damage to the roof itself."[254] General contractors and roofing contractors are strongly encouraged to have disclaimers and damage limitation provisions in their contracts to address this risk. It has also been recommended that roofing contractors consider indemnification protections if they elect to work with a solar panel installation contractor.[255]

CertainTeed, a subsidiary of Saint-Gobain, is a leading North American brand of exterior and interior building products—including roofing, siding, fence, decking, railing, trim, insulation, drywall, ceilings, and solar. In a 2019 interview with the Manager of Solar Product Development and Marketing at CertainTeed, it was acknowledged that the industry is seeing more large roofing companies becoming more involved in solar. There is a "natural alignment and synergy between solar and roofing throughout the value chain which is organically pulling the two industries together."[256] The solar industry is maturing, products are becoming easier to install, and improved software has simplified both system design and sales. These factors bundled together have made it easier for roofing contractors to participate in the solar market. In addition, they are also seeing solar installers (particularly those working in more developed solar markets) starting to provide roofing as a supplemental service. As solar costs continue to decrease, there will likely be corresponding adoption of solar roofing products.[257]

The advantages of installing solar and roofing together include “better warranty protections, more consistent supply chains, product innovation, more affordable pricing and greater customer satisfaction.”[258] A disadvantage may relate to learning curves in understanding the newer product. Roofing contractors and solar installers have worked separately for a long time. When these groups come together—either as closely intertwined strategic partners or, more specifically, as a single company providing both services—there can be a learning curve in terms of understanding the nuances of the newer market (roofers will need to become experts in solar and solar installers will need to develop expertise in roofing).[259]

The traditional siloed nature of roofing companies doing roofing and solar companies doing solar has been discussed as an obstacle to solar roofing product adoption. The industry has seen an uptake in these two trades coming together and this is helping to eliminate one of the primary obstacles to the broader adoption of solar roofing products and other BIPV solutions.[260]

There has been some discussion of advantages and disadvantages of using roofing channels—such as roofing product and/or building product distributors—to move solar technologies and products. The major advantage with this model is that the roofing channel is more firmly established, compared to the solar industry. That level of maturity correlates with well-established infrastructure, process efficiency, and ultimately lower costs for customers. The disadvantage with using roofing channels to move solar products is a lack of technical knowledge. The roofing channel partners may not be as familiar with solar products, compared to traditional solar channels.[261]

Solar installation companies and roofing companies looking to work collaboratively, or even those looking to provide both services, may benefit from training programs and networking opportunities provided by product manufacturers. In addition, professional roofing and solar associations may be an excellent resource for bringing the groups together and encouraging collaboration. Certain manufacturers may offer incentives to contractors who become credentialed on their products. These incentives may include lead generation, promotional assistance, and marketing materials.[262]

As referenced earlier in this report, the National Renewable Energy Laboratory published a report titled *Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030* in January 2018. This source discusses the nature of the relationship that exists between roofing and solar companies.

According to the NREL report, the business models of solar and roofing companies are generally well aligned and it is believed by a number of industry stakeholders that collaboration among these companies is likely to increase. However, “the need to have experienced solar sales professionals on staff can pose a barrier to roofing companies that want to sell PV directly to consumers.”[263] The expertise needed to sell PV is drastically different than the expertise needed to sell roofs. Solar sales professionals are likely to be more knowledgeable with respect to residential utility rate structures and consumer load profiles, whereas roofers may not be as familiar with these topic areas. Roofing companies would need to train existing sales staff or hire solar sales professionals to sell PV and roofing products together. In addition, incorporating PV into a roof replacement can cost more than a roof replacement alone—in many cases, PV sales are not guaranteed.[264]

It has also been suggested by industry experts that improved permitting, inspection, and interconnection (PII) processes are required for solar/roofing companies to realize the cost savings of business model integration. Under many authorities having jurisdiction (AHJs), a new roof and the accompanying PV installation are treated as two individual projects when it comes to permitting and inspection (this is the case even for integrated products). Combining the permitting and inspection processes for the new roof and the PV installation would be more cost effective and it would allow for faster project completion. The lack of standardization in PV permitting, interconnection requirements, and fees across more than 18,000 authorities having jurisdiction and 3,000 utilities also hinders installers in deploying PV rapidly across multiple jurisdictions and utility territories. While some states are moving toward standardization, generally speaking, roofing companies may consider the lack of PV PII standardization to be a financial risk. This may deter them from expanding product offerings to include PV.[265]

6.5 ROOFERS & SOLAR INSTALLERS: FACTORS HINDERING COLLABORATION

There are a few noted obstacles that are preventing roofers from partnering more frequently with solar PV companies, or doing more with solar, in general. Roofing and solar companies have historically run into a few issues when working together. If a new roof is required prior to installing solar, the contractors often have different levels of availability and their timelines do not always match up, causing some potential complications and inconveniencing solar companies, builders, and/or home or building owners.

The increasing number of roof penetrations can cause problems if work is not performed perfectly. Some roofers might be hesitant to recommend solar if the solar PV installation would potentially interfere with the warranty or integrity of the roof, itself. There can be a lot of “finger pointing” that goes on if a roof leaks after the installation of solar PV. Many roofers automatically void a new roof’s warranty after a solar company makes penetrations to the roof.

Certain types of roofing materials—which may be used more frequently in certain areas or regions—are not always as compatible with solar panels or other solar PV technologies. Approximately 75% of roofs in the United States are made of asphalt shingles. While these asphalt shingle roofs are compatible with solar panels, the life of the roof is only about 15-20 years, whereas the average lifespan of a residential PV system is about 20-30 years (this requires the disassembly of the PV array, re-roofing, and re-assembly, which can be costly).[266] Metal roofs are increasing in popularity. Over 2 billion square feet of metal roofing is installed in the U.S. annually and this number is growing each year. Metal roofs are more durable and have a significantly longer lifespan, compared to a traditional roof with asphalt shingles. A metal roof would outlast the life of a solar PV system, which would eliminate the need for that costly disassembly of the PV system, re-roofing, and re-assembly. It is also easier and less expensive to mount solar to a metal roof.[267] The industry might see more cooperation and solar integration among roofers specializing in metal roofing. Conversely, other types of roofing are not as compatible with solar, and companies specializing in those types of roofs may be less inclined to partner with a solar company because installing solar PV would be more likely to cause roof damage. For example, clay tile roofs are very popular across the Southwest region of the United States. These roofs are quite durable and can last for 100 years, but installing solar on clay tiled roofs has been more expensive and riskier than installing solar on other roof types. The tiles are relatively expensive, fragile, and removing them to install the roof mounts for solar panels can interfere with the seal and lead to water damage.[268] This, of course, is more of an issue with roofing companies and solar PV panel installers—this factor would likely have less of an impact on roofing companies and their adoption of BIPV technologies like solar shingles or other more integrated solar roofing products.

When it comes to roofers who are also the solar PV installers, challenges may include increased costs associated with compliance, as well as increased liability. Homeowners have filed claims against solar installers for failing to meet performance standards and these claims would fall on roofing companies that are also installing the solar panels. Roofers could lessen the impact of this risk by addressing the issue in their contracts, but it may still be an issue to consider, nonetheless. The learning curve that may come with trying to understand a new product has been cited as another potential challenge. Roofing contractors and solar installers have worked separately for a long time. As these groups come together (either as strategic partners or as a single company providing both services) there can be a learning curve in terms of understanding the nuances of the newer market.[269]

Generally speaking, the fact that roofing companies and solar companies have operated as separate and siloed entities for so long is an obstacle to solar roofing product adoption, in itself.[270] The expertise needed to sell PV is very different than the expertise needed to sell roofs. The need to have experienced solar sales professionals on their staff can be a barrier for roofing companies that want to sell PV directly.[271] Solar sales professionals will typically know much more about residential utility rate structures and consumer load profiles, whereas roofers may lack expertise in this area. To successfully integrate roofing and solar, roofing companies would need to train existing sales staff or hire solar sales professionals to sell PV and roofing products together. Cost can also be a factor. Incorporating PV into a roof replacement can cost more than a roof replacement alone. Sales of solar PV are not guaranteed and might be a tough sell for some builders and home or building owners.[272]

Improved permitting, inspection, and interconnection—collectively referred to as "PII"—processes are necessary if solar and roofing companies are going to fully realize the cost savings that will result from an integration of the business models. As noted by NREL and the industry experts they interviewed a few years ago, many authorities having jurisdiction (AHJs) treat a new roof and the accompanying PV installation as two separate projects in terms of permitting and inspection (and this is even true for integrated products). Combining the permitting and inspection process for both the new roof and the PV installation would be more cost effective and it would accelerate the time to project completion. The general lack of standardization in PV permitting, interconnection requirements, and fees across AHJs and utilities is also making it more challenging for installers who want to deploy PV rapidly across multiple jurisdictions and utility territories. While some states are starting to recognize this issue and they are moving toward standardization, it continues to be a problem for builders and other contractors. Roofing companies may consider the lack of PV PII standardization to be a financial risk, which would deter them from expanding product offerings to include PV.[273]

Industry experts have proposed suggestions for overcoming some of these obstacles and challenges. Solar installation companies and roofing companies who want to work collaboratively (or companies looking to provide both services) may benefit from training programs and networking opportunities provided by product manufacturers. Professional roofing and solar associations may also be an excellence resource for bringing the groups together and encouraging collaboration. The National Roofing Contractors Association (NRCA) is a key industry group for the roofing segment (there are a number of regional and state industry groups that are NRCA affiliates, as well) and the Solar Energy Industries Association (SEIA) is a key industry group for the solar segment. In addition, some manufacturers may offer incentives (lead generation, promotional assistance, marketing materials, etc.) to contractors who become credentialed on their products.[274]

6.6 ROOFERS & SOLAR INSTALLERS: FACTORS ENCOURAGING COLLABORATION

While there are some obstacles and limitations hindering the collaboration of roofers and solar installers, there are also a number of factors encouraging collaboration among these key stakeholder groups. When roofing and solar PV installation services are provided by a single company, this streamlines the job of the general contractor, as they only have to hire one company to perform both roof and solar installation.[275] Homebuilders are starting to establish relationships with companies—notably manufacturers and installers—that provide both roofing and solar solutions. This model leverages efficiencies related to both cost and labor and it streamlines the process for the builder.

From the perspective of the installer, being able to sell two products instead of one (roofing and solar versus roofing or solar) will improve their revenue generation and enable cost efficiencies which can further improve profitability. This factor may also benefit the builder or homeowner, as it could translate to greater savings for them, as well.[276]

When roofing companies are also responsible for installing the solar panels or solar PV technology, there is a resulting reduction in defect claims. There can be issues among the roofer, solar installer, builder, and building owner or homeowner if problems with the roof occur after the installation of solar PV. Roofing contractors may prefer to perform the solar installation themselves to ensure adequate work, thorough inspection, a single contract, and a single warranty, among other factors.[277] Solar companies are adding roofing to their list of services for many of the same reasons. If a solar company can also provide roofing services, this can streamline the customer experience, prevent a backlog of solar projects, and enable them to bundle warranties.[278]

There are benefits of collaboration and partnership for both roofing and solar installation companies. Roofing companies can ask homeowners if they have ever considered solar and, if interest is there, they can sell that lead to a solar installer. Roofing companies can also complete a more thorough qualification process to ensure that solar is a viable option for the home or building owner, and then sell that qualified lead to a solar installer. This qualified lead could include information such as qualification for the solar federal tax credit, their motivation for going with solar, the name of their electric utility and usage information, and the age of their roof. Roofers can partner with solar installers in such a way that the roofing company would actually sell the PV system to the home or building owner, but work with a third-party solar company to install the PV system.[279] These partnerships may also benefit roofing companies, in that solar installers may bring leads to the roofers.[280] If a roof is older, it may be more economical to have the roof replaced before installing solar PV. About 75% of roofs in the U.S. are made of asphalt shingles and the average lifespan for that type of roof is approximately 15-20 years, whereas the average lifespan of a residential PV system is about 20-30 years. It may be more cost effective to have the roof replaced right before installing the PV system, to avoid having to remote the solar PV system, re-roof, and re-install the solar PV system a few years down the line. One source has also stated that approximately 20% of residential solar jobs are not completed by the PV installer because the home needs a new roof at the time of installation.[281] Collaboration among roofing companies and solar PV installers could be beneficial to both from a financial perspective.

A number of experts have noted that the industry is, in fact, seeing an increasing number of large roofing companies becoming more involved in solar. According to the Manager of Solar Product Development and Marketing at CertainTeed, there is a "natural alignment and synergy between solar and roofing throughout the value chain which is organically pulling the two industries together."[282] The solar industry is maturing, products are becoming easier to install, and improved software has simplified both system design and sales. All of these factors are making it easier for roofing contractors to enter the solar market. The industry is also seeing solar installers (particularly those working in more developed solar markets) starting to provide roofing as a supplemental service. As the cost of solar continues to decrease, it is believed that there will be corresponding adoption of solar roofing products.[283] The advantages of installing solar and roofing together include "better warranty protections, more consistent supply chains, product innovation, more affordable pricing and greater customer satisfaction."[284]

Historically, roofing and solar PV installation have been treated as two distinct services and this was an inherent obstacle to solar roofing product adoption. With that said, the industry has witnessed an uptake in the two trades coming together and this is helping to eliminate that key obstacle to broader adoption.[285] According to the report from NREL, the business models of solar installers and roofing contractors are generally well aligned and many industry experts believe that collaboration among these companies is likely to increase.[286]

6.7 INSIGHTS FROM PRIMARY RESEARCH

Resources from the National Association of Home Builders (NAHB) were consulted for this section, and additional feedback was received from this association. The NAHB has seen an increasing number of inquiries over the past year from builders about integrating rooftop solar PV into their offerings, but not as much regarding BIPV, specifically. Many of the members of their Sustainability & Green Building subcommittee make their homes solar PV-ready or incorporate rooftop solar if the customer wants it, and they usually do so through a solar installer partner (as opposed to installing the PV system themselves). That being said, they recognize that those subcommittee members comprise a very small percentage of the overall association. While they do have some members that can incorporate rooftop solar, that knowledge is not necessarily widespread to an average builder member. Last year, the NAHB created a Solar Toolkit for Builders, designed to help builders who may have limited to no knowledge of solar PV get started in this space. The NAHB is working with a few other entities on a project led by the National Renewable Energy Laboratory (NREL), which will take place over the next few years and will focus on barriers to rooftop solar PV in new construction and re-roofing projects.

7.0 Modeling & Simulation Tools

7.0 MODELING & SIMULATION TOOLS

This section discusses state-of-the-art modeling and simulation tools that are used to address issues related to shading in complex buildings and facades. Models and tools that can help stakeholders understand how much electricity a BIPV system is likely to generate would be helpful, as this information would be valuable in terms of assessing the relative advantages and disadvantages of BIPV technologies.

7.1 BIPV DESIGN AND PERFORMANCE MODELING TOOLS AND METHODS

In October 2019, a report titled *BIPV Design and Performance Modelling: Tools and Methods* was released in association with the International Energy Agency (IEA) Photovoltaic Power Systems Programme. This report was written as part of IEA PVPS Task 15—"an international collaboration to create an enabling framework and to accelerate the penetration of BIPV products in the global market of renewables and building envelope components, resulting in an equal playing field for BIPV products, Building Applied PV (BAPV) products and regular building envelope components, respecting mandatory, aesthetic, reliability and financial issues."[287] Members of IEA PVPS Task 15 include Austria, China, Belgium, Canada, Denmark, France, Germany, Italy, Japan, Korea, Norway, The Netherlands, Spain, Sweden, and Switzerland. In this report, the authors discuss BIPV design, environmental considerations, BIPV performance modeling, building performance simulation, economics, and they provide a comparative analysis of available BIPV modeling tools.

The report includes a detailed comparative analysis of many BIPV design and management tools that are currently available and in use. The tools fall into four different categories—standalone tools, CAD/BIM, online tools, and apps. The tools in the various categories include the following:

Standalone Tools

- System Advisor Model (SAM) (2017.1.17)
- RETScreen Expert
- Homer Pro
- PV *SOL Expert
- PV Scout
- Solar F-Chart
- Sunulator
- Pvsyst
- Helios 3D solarparkplanung
- Polysun
- INSEL
- Aurora
- ArcGIS

› SolarPro
› BIMsolar
› SolarBIM PV
› Helioscope
› PV-DesignPro
› PVComplete
› Solar Pro
› Solergo
› BLUESOL

CAD/BIM Tools

› Solarius-PV
› Skelion
› INSIGHT (solar analysis tool) for Revit
› Ladybug Tools
› DDS-CAD PV (Polysun)

Online Tools

› Construct PV
› Archelios
› PV watts
› PV GIS
› CalculationSolar.com
› PV*SOL Online
› EasyPV
› Solar Estimate
› SOLARGIS – PVPLANNER

Apps

› EasySolar
› Onyx Solar
› PVOutput
› SMA Sunny Portal

The following tables are as they appear in the referenced IEA report.

Table 26: Analysis of Stand Alone BIPV Design and Management Tools (part 1) (IEA Photovoltaic Power Systems Programme)[288]

			Stand Alone																					
			System Advisor Model (SAM) 2017.1.17	RETScreen Expert	Homer Pro	PV *SOL Expert	PV Scout	Solar F-Chart	Sunulator	Pvsyst	Helios 3D solarparkplanung	Polysun	INSEL	Aurora	ArcGIS	SolarPro	BIMsolar	SolarBIM PV	Helioscope	PV-DesignPro	PVComplete	Solar Pro	Solergo	BLUESOL
BIPV design	BIPV Planning	Conceptual/early phase (LOD 100)				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Schematic (LOD 200)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Design development (LOD 300-500)	●	●	●	●	●			●	●			●			●		●	●	●	●	●	
	Building Type	Residential	●	●	●	●						●		●	●		●		●		●	●		
		Commercial	●	●	●	●						●		●	●		●					●		
		Industrial		●	●												●							
		Other (community, heritage, etc.)		●	●																			
	Interactive design	Building 3D modelling				●				●	●			●	●	●	●		●			●		●
		Building 2D modelling					●					●				●		●			●		●	●
		Visualisation/geo maps	●			●					●			●	●	●	●		●			●		
	Building Standards																●							
	Building integration	Simple (BIPV Category A-B Roof)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Complex (BIPV Category C-E		●						●		●	●		●	●	●					●		
Environment	Terrain/ Surroundings	Simple - GIS LOD 0-2/Terrain 1-2	●	●	●	●	●		●	●	●	●		●	●		●		●		●	●	●	●
		Complex - GIS LOD 2-4/Terrain 3-4				●	●				●				●		●		●		●	●		
		GIS Database/Maps				●					●												●	
		Import external data				●				●	●						●		●				●	
	Weather Data	Meteorological/Statistical data	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●	●
		Satellite-based data (Hybrid)		●						●		●		●	●	●					●	●		●
		Import external data	●	●	●	●		●		●						●	●					●	●	●
BIPV Performance Modelling	Irradiance on PV	Simple 2D - POA		●				●	●															
		Simple 2D - POA with shading	●	●	●	●	●			●	●	●		●	●	●		●	●	●	●	●	●	●
		Complex 3D - Raytracing															●							
		Complex 3D - Other																						
		Import external data		●																				
	Loss	DC/AC	●	●	●	●				●	●		●	●	●	●	●	●	●	●	●	●	●	
		Snow/Soiling	●	●	●	●				●	●		●				●	●	●	●	●	●	●	
		Temperature	●	●	●					●	●	●					●	●	●	●	●	●	●	
		Wind	●	●						●		●												
		Other	●	●	●	●				●	●		●	●			●		●			●	●	
	PV Performance Models	Equivalent circuit 1 or 2 diode								●						●	●		●				●	
		Empirical fitting (point-value)	●		●			●	●		●			●	●					●				
		Proprietary		●		●	●					●	●									●		
	Spatial Resolution	System	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
		Module	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●	●	●	●	●	
		Cell																						
	Temporal Resolution	Monthly	●	●	●			●	●			●				●		●						
		Hourly	●	●	●	●				●	●	●	●		●	●	●	●	●	●	●	●	●	
	PV Cell Technologies	1st generation PV Cells	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●	
		2nd and 3rd gen. PV Cells	●	●	●	●					●	●	●			●	●	●	●	●	●	●	●	
	Databases	BIPV modules	●	●	●	●	●	●		●	●	●	●	●		●	●	●	●	●	●	●	●	●
		Inverters	●	●	●	●	●	●		●	●	●	●	●		●	●	●	●	●	●	●	●	●
		Batteries	●	●	●	●	●	●		●		●					●			●			●	●
		Other - BOS					●				●	●		●					●					●
		Import external data	●		●	●																		
	Grid Type	Stand-alone off grid		●	●	●	●	●	●	●	●	●	●			●	●			●			●	●
		Grid-tie	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		●	●	●
	Grid Specifications	Voltage		●	●	●	●			●		●						●					●	
		Number of phases			●	●	●			●		●						●					●	
		Power factor			●	●	●			●		●						●					●	

Table 27: Analysis of Stand Alone BIPV Design and Management Tools (part 2) (IEA Photovoltaic Power Systems Programme)[289]

			Stand Alone																					
			System Advisor Model (SAM) 2017.1.17	RETScreen Expert	Homer Pro	PV *SOL Expert	PV Scout	Solar F-Chart	Sunulator	Pvsyst	Helios 3D solarparkplanung	Polysun	INSEL	Aurora	ArcGIS	SolarPro	BIMsolar	SolarBIM PV	Helioscope	PV-DesignPro	PVComplete	Solar Pro	Solergo	BLUESOL
Building Simulation	Structural	Load Simulation																						
	Energy demand	Data Simulation	●		●	●										●							●	
		Data Import/Load profile	●	●	●				●			●		●			●						●	
	Energy Price		●	●	●			●	●	●		●	●			●							●	●
	Emissions	CO2 reduced		●	●	●			●							●							●	
		CO2 embedded																						
	Other	Heat Island Effect																				●		
		Indoor Environment																						
	Optioneering	Multiple solutions		●	●													●	●		●			
		Integrated optimization			●	●													●					
Economics	Costs	Capital cost / BOQ prices	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●		●	●	●	●
		O&M cost	●	●	●	●	●	●	●	●	●	●	●			●		●					●	
	Benefits	Reduction of Energy Bills	●	●	●	●		●	●	●		●				●							●	
		Building Material Cost Offsets																						
		Reduction of Transmission Loss																						
		Reduction of Carbon Cost		●													●						●	
	Finance Modes	Direct Finance	●	●		●		●	●	●		●				●		●					●	
		Loan/Lease/Mortgage	●	●		●	●	●	●	●		●				●		●						
		PPA	●															●						
	Financial Analyses	LCC/NPV	●	●	●	●		●	●		●	●	●	●			●	●	●	●	●	●	●	●
		Simple payback	●	●					●		●	●	●	●		●	●	●	●	●	●	●	●	●
		IRR	●	●	●							●	●	●			●	●	●	●	●		●	●
		Profitability Index/ROI/LCOE	●	●	●								●	●			●	●	●	●	●	●	●	●
		Sensitivity Analysis		●	●							●												
		Cashflow	●	●	●	●		●						●			●	●	●	●			●	●
	Government Incentives	Incentive Database	●	●																			●	
		Feed in Tarrifs		●		●	●	●	●	●			●			●	●				●		●	●
		Other Incentives	●	●				●	●			●											●	●
		Regulations/Policies		●					●								●				●			

Table 28: Analysis of CAD/BIM, Online, and App BIPV Design and Management Tools (part 1) (IEA Photovoltaic Power Systems Programme)[290]

			CAD/BIM					Online									Apps			
			Solarius-PV	Skelion	INSIGHT (Solar analysis tool) for Revit	Ladybug Tools	DDS-CAD PV (Polysun)	Construct PV	Archelios	PV watts	PV GIS	CalculationSolar.com	PV*SOL Online	EasyPV	Solar Estimate	SOLARGIS – PVPLANNER	EasySolar	Onyx Solar	PVOutput	SMA Sunny Portal
BIPV design	BIPV Planning	Conceptual/early phase (LOD 100)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Schematic (LOD 200)	●	●	●	●	●	●	●	●		●	●	●			●			●
		Design development (LOD 300-500)	●		●	●		●	●											
	Building Type	Residential		●	●	●	●	●		●			●		●					
		Commercial			●	●	●	●		●			●		●					
		Industrial			●	●		●												
		Other (community, heritage, etc.)			●	●														
	Interactive design	Building 3D modelling	●	●	●	●	●	●	●											
		Building 2D modelling	●		●	●								●			●			
		Visualisation/geo maps	●	●	●	●			●	●							●			
	Building Standards													●						
	Building integration	Simple (BIPV Category A-B Roof)	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●
		Complex (BIPV Category C-E			●	●	●	●	●		●			●						
Environment	Terrain/ Surroundings	Simple - GIS LOD 0-2/Terrain 1-2	●	●	●	●	●	●	●		●									
		Complex - GIS LOD 2-4/Terrain 3-4	●	●	●	●	●	●	●											
		GIS Database/Maps		●	●	●			●											
		Import external data	●	●	●	●	●		●		●									
	Weather Data	Meteorological/Statistical data	●	●	●	●	●	●	●		●					●				
		Satellite-based data (Hybrid)	●			●	●				●					●				
		Import external data	●			●			●		●					●				
BIPV Performance Modelling	Irradiance on PV	Simple 2D - POA				●					●	●	●					●	●	
		Simple 2D - POA with shading	●	●		●	●	●	●	●	●			●	●	●	●			●
		Complex 3D - Raytracing			●	●			●											
		Complex 3D - Other																		
		Import external data	●			●					●									
	Loss	DC/AC	●			●			●	●	●		●			●				
		Snow/Soiling	●			●			●	●	●		●							
		Temperature	●	●		●	●			●	●									
		Wind				●	●													
		Other	●			●			●	●	●		●			●				
	PV Performance Models	Equivalent circuit 1 or 2 diode				●			●											
		Empirical fitting (point-value)	●	●		●		●		●	●	●	●	●	●	●	●	●	●	●
		Proprietary			●		●													
	Spatial Resolution	System	●	●	●	●	●	●	●	●		●			●	●	●	●	●	●
		Module	●	●	●	●	●	●	●	●	●		●	●			●			●
		Cell				●														
	Temporal Resolution	Monthly					●					●	●	●		●	●	●	●	
		Hourly	●	●	●	●	●	●	●	●	●									●
	PV Cell Technologies	1st generation PV Cells	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		2nd and 3rd gen. PV Cells	●	●	●	●	●	●	●	●	●			●		●				
	Databases	BIPV modules	●			●	●	●	●	●		●	●	●			●		●	
		Inverters	●			●	●	●	●	●		●	●	●			●		●	
		Batteries	●				●		●			●		●						
		Other - BOS					●					●		●						
		Import external data																		
	Grid Type	Stand-alone off grid	●				●		●	●	●	●								
		Grid-tie	●				●		●	●	●	●	●			●	●	●	●	●
	Grid Specifications	Voltage	●				●					●								
		Number of phases	●				●													
		Power factor					●													

Table 29: Analysis of CAD/BIM, Online, and App BIPV Design and Management Tools (part 2) (IEA Photovoltaic Power Systems Programme)[291]

			CAD/BIM					Online									Apps			
			Solarius-PV	Skelion	INSIGHT (Solar analysis tool) for Revit	Ladybug Tools	DDS-CAD PV (Polysun)	Construct PV	Archelios	PV watts	PV GIS	CalculationSolar.com	PV*SOL Online	EasyPV	Solar Estimate	SOLARGIS – PVPLANNER	EasySolar	Onyx Solar	PVOutput	SMA Sunny Portal
Building Simulation	Structural	Load Simulation			●									●						
	Energy demand	Data Simulation	●		●	●			●			●	●				●		●	
		Data Import/Load profile			●	●	●								●				●	●
	Energy Price		●		●		●		●	●				●	●		●			●
	Emissions	CO2 reduced	●									●	●	●			●	●		
		CO2 embedded																		
	Other	Heat Island Effect			●	●														
		Indoor Environment			●	●														
	Optioneering	Multiple solutions			●	●														
		Integrated optimization			●	●														
Economics	Costs	Capital cost / BOQ prices	●		●	●	●		●					●	●		●	●		
		O&M cost	●		●	●	●		●					●	●		●	●		
	Benefits	Reduction of Energy Bills	●		●	●	●		●				●	●			●	●		
		Building Material Cost Offsets																		
		Reduction of Transmission Loss																		
		Reduction of Carbon Cost																		●
	Finance Modes	Direct Finance					●		●					●			●			
		Loan/Lease/Mortgage					●		●					●			●			
		PPA																		
	Financial Analyses	LCC/NPV	●		●	●	●		●					●	●					
		Simple payback	●		●	●	●		●					●				●		
		IRR	●				●		●					●				●		
		Profitability Index/ROI/LCOE			●	●			●									●		
		Sensitivity Analysis			●	●	●													
		Cashflow	●														●			
	Government Incentives	Incentive Database																		
		Feed in Tarrifs	●						●					●			●			
		Other Incentives					●		●								●			
		Regulations/Policies																		

7.2 SYSTEM YIELD MODELING

When exploring the use of BIPV, particularly in shaded areas, several technical gaps frequently surface, including the need for modeling tools.

As noted in a September 2020 conference paper from EU PVSEC, the largest international Conference for Photovoltaic research, the market uptake for BIPV has been held back by industry challenges to provide holistic solutions that meet the key demands from decision makers and end-users. "The most important technological challenges toward energy-efficient buildings are twofold: (i) bioclimatic design, considering eco-friendly sources as well as renewable and durable materials, and (ii) Building Information Modelling (BIM) methodology for the whole architecture, engineering and construction (AEC), involving design, production and process innovation respectively.*"*[292] The research advocates that one of the key challenges in this area is fragmentation of the value chain and a lack of digitization, challenges that are being address by the previously introduced European H2020 projects, PVSITES and BIPVBOOST, both of which address, "the need for a software solution within a digital environment for the joint modelling, performance simulation and information management of BIPV and building energy systems."[293]

BIM (Building Information Modeling) is commonly defined as, "an intelligent 3D model-based process that provides architecture, engineering, and construction (AEC) professionals the insight and tools to more effectively plan, design, construct, and manage buildings and infrastructure."[294] The topic of BIM as a tool for BIPV modeling and eventual adoption surfaces frequently in the literature, including in a report from BIPVBOOST titled, *Information Modelling/Management for BIPV Cost-Reduction. Digital Adoption Plan and Guideline for a Data-Driven BIPV Process and Optimization Strategies*.[295] The document from BIPVBOOST addresses information modeling and management to support BIPV cost reduction and adopting a BIM-based approach for the implementation of novel BIM tools with new functionalities in this area.[296]

7.3 ACADEMIC AND RESEARCH OFFERINGS

Researchers at the Fraunhofer Institute for Solar Energy Systems ISE appear to be at the forefront of research in BIPV, including in modeling tools. The institute works collaboratively with industry partners on a wide array of BIPV research and services and boasts considerable mass market level, which includes the planning, construction, operation and maintenance. As such, BIPV must be widely available in Building Information Modeling (BIM).

The REMod (Regenerative Energy Model) from the German Fraunhofer institute was developed in 2013.[297] This tool was recently used in the article, "Review of Technological Design Options for Building Integrated Photovoltaics (BIPV)," published in *Energy & Buildings*. This article referenced three additional papers discussing BIPV modeling.

- Light Attenuation Model to Predict Nominal Power of Modules with Light-Scattering Ceramic Printed Front Glasses, which discusses "Applying a matrix-based approach, we developed a light attenuation model, which can describe the relative transmittance decrease of glass panes in air and relative power decrease of modules for glass covers with arbitrary coverage ratios."[298]

- Detailed modeling of building-integrated photovoltaics - from component and environmental data to the system output discusses using a tool from Sandia Labs called RADIANCE.

- A comprehensive study on partial shading response of c-Si modules and yield modeling of string inverter and module level power electronics, and this article discusses the development of a modeling tool, "A simulation model is developed to quantify the benefits and drawbacks of different PV system architectures. The model includes a shading evaluation of the installation with means of 3D modeling, irradiance calculations, PV cell modeling and finally an empirical power conversion model."[299]

In September 2020 additional research came out of the Fraunhofer Institute—titled "Energy Yield Modelling of 2D and 3D Curved Photovoltaic Modules." This paper "presents a detailed model to simulate the energy yield potential of various designs of curved PV modules depending on their bending angle, orientation and location."[300] This research uses datasets Solcast for its simulations with MATLAB'S PVLIB toolbox. The Fraunhofer Institute has published numerous papers and carried out research projects over the past decade, if not further back, search results in this topic area frequently tie back to research from this group.

Another tool from Fraunhofer that surfaces in the literature is OPTOS that offers simulations for the determination of reflection and absorption of solar cells with surfaces textured on both sides.

A research paper out of Eindhoven University of Technology in the Netherlands titled, "Modeling of Partially Shaded BIPV Systems – Model Complexity Selection for Early-Stage Design Support," evaluates which cases PV system models are applicable for early-stage building design support using a tool called PVMismatch. The method was tested on different geometries and was able to predict under what conditions the linear model would overestimate the PV performance.[301]

A case report titled, "A Preliminary Techno-Economic Study of a Building Integrated Photovoltaic (BIPV) System for a Residential Building Cluster in Sweden by the Integrated Toolkit of BIM and PVSITES," proposed a simulation process using "the BIM platform as the foundation for the design, modelling, and exporting to other simulation tools."[302] This "allows for faster iterations not only in the different simulation scenarios but also in the building model, if changes were necessary." [303] It appears that the tool used in this study is BIMsolar & PVSITES plugins, which was developed by CADCAMation (Switzerland), and addresses the need for a software tool for the joint simulation of BIPV products and building energy performance.

With respect to Heritage Building Information Modeling (HBIM) and the use of BIPV in historic buildings, a 2020 paper titled "Building-Integrated Photovoltaics (BIPV) in

Historical Buildings: Opportunities and Constraints," from Sapienza University of Rome discusses modeling tools for these unique structures.

Another paper discussing issues of shading and urban environments was published by French researchers in 2018 and specifically addresses limitations and challenges posed by modeling tools: "Simulating solar irradiation and photovoltaic energy production at city scale is a considerable technological challenge… In this study the simulations have been performed with the version 4.3 of the software ENVI-met. ENVI-met is a prognostic, three-dimensional, high-resolution microclimate model. The model is specifically designed to simulate the urban climate taking into account all the phenomena specific to this type of environment."[304]

Researchers at Switzerland's Ecole Polytechnique Fédérale de Lausanne (EPFL) are working on using 3D LiDAR data in urban BIPV modeling and simulation where they developed CitySim[305] software. The tool is discussed alongside other tools in the 2016 paper, "3D Model for Solar Energy Potential on Buildings from Urban LiDAR Data."[306]

Researchers in Belgium are looking at a multi-physics BIPV model for the simulation of BIPV facades within the openIDEAS framework for building and district energy simulations, noting that the combination of these two modelling approaches is not common in BIPV models, particularly for building performance simulations. The research paper reports that using this method, daily energy yield estimation error is on average below 3 % and the error in the monthly energy yield is below 2%.[307]

Other methods being looked at approach the challenge of BIPV modeling by combining several tools and methods. Research led by researchers in the UK and carried out in Turkey used the Python-based Algorithm editor Grasshopper to interlink four types of modelling and simulation tools as 1) generation of 3-D model, 2) solar radiation analysis, 3) formatting weather files (TMY data set) and 4) dynamic energy demand. The method has been demonstrated for a cluster of 20 buildings located in the Yasar University in Izmir (Turkey).[308]

Also out of the UK, one paper presents and describes a model, solarscene.xyz, developed at the Centre for Renewable Energy Systems Technology (CREST) capable of generating high resolution maps of solar energy potential for existing and planned building locations. The tool is now available for free.[309]

"A Novel BIPV Reconfiguration Algorithm for Maximum Power Generation under Partial Shading" was published by researchers in Qatar and discusses the partial shading on the roof, using a station that is modelled using building-information modelling (BIM) software to illustrate the BIPV and indicate the solar insolation distribution on the rooftop by simulating the station's rooftop.[310] The modeling of the BIPV system was done in MATLAB/Simulink.[311]

Additional research that has reached the prototype level was recently carried out in China along with a researcher from Belgium. This research group proposed a uniform BIPV design platform called e-BIM, which is a BIM-centric BIPV design and analysis software platform that seeks to address the related design concerns via one uniform data model. As noted in the article, the current prototype is developed based on Autodesk® Revit and has been tested in a practical BIPV application. These tests indicate that this platform achieves seamless BIPV design for architects, PV system designers and electricity professionals, along with an 11.7% cost reduction in the photovoltaic system cost and a 2.95% reduction in transmission losses compared to the initial BIPV design.[312]

7.4 PROMISING BIPV MODELING & SIMULATION TOOLS

This section identifies state-of-the-art tools used for BIPV modeling and simulation. The tools explored surfaced through the report titled *BIPV Design and Performance Modelling: Tools and Methods* (this October 2019 report was released in association with the International Energy Agency (IEA) Photovoltaic Power Systems Programme), as well as through a search of the academic literature and other publicly available sources. When relying on secondary research alone, it was not always clear if a PV modeling tool was also suitable for BIPV. To be as thorough as possible, we reached out to several companies and organizations for clarification regarding their modeling and simulation tool and its capabilities. When reaching out to providers and/or developers of BIPV/PV modeling and simulation tools, these were the questions that were asked:

1. Is your solution suitable for modeling BIPV (as opposed to just traditional rooftop PV)?
2. Does your modeling tool account for surrounding buildings?
3. Does the modeling tool account for complex shading?
4. Does the modeling tool provide information pertaining to system yield?
5. Does the model include solar heat gain coefficients and impact on building thermal loading?

We reached out to a total of 21 organizations to ask about their BIPV and/or PV modeling and simulation tools. We received responses from 11 organizations (not all of them were capable of modeling BIPV). Based on the primary and secondary research conducted, the following modeling and simulation tools appear to be the best-in-class tools for BIPV modeling.

In addition to those profiled below, there are also a number of modeling and simulation tools more broadly used for solar PV. Some of these tools may also be useful for BIPV projects, but if product descriptions did not specifically indicate BIPV application and the organizations developing or providing those tools did not respond to our request for additional product information, they have been placed in the Appendix.

7.4.1 EURAC RESEARCH – INSTITUTE FOR RENEWABLE ENERGY

Eurac Research is a private research center based in Italy. Eurac Research is affiliated with the Institute for Renewable Energy, which conducts applied research on advanced energy systems related to sustainable energy sources. The organization supports national and international research projects and they work collaboratively with industry partners.[313]

BIPV is one of the applied research fields of Eurac Research. Within the Eurac Institute for Renewable Energy, a group of experts on PV energy systems carry out a number of activities centered around the analysis of solar resources, the performance and reliability of PV modules and systems, and their integration into buildings and the grid. The primary goal of this group is to increase BIPV penetration in the building sector, overcoming the barriers that exist in the market.[314]

In speaking with industry experts and key stakeholders, Eurac Research has recognized that some barriers to BIPV adoption still exist and many issues relate back to the design phase of BIPV. The lack of intuitive and effective software tools for the early design of BIPV projects was cited as a hurdle for the BIPV segment. In an effort to address this barrier, Eurac Research has developed a new software tool for the early design phase of BIPV systems. This tool provides designers with the optimal BIPV system configuration of PV modules and electric storage based on local weather, shading patterns, the cost of resources and technology, and the technical characteristics of different PV systems on the building envelope. Designers can leverage this tool to optimize the energy balance of the system, ensure the payback, and maximize earnings after a set period of time. The inputs that are required in order to obtain accurate and realistic results are easily accessible to designers, and the tool provides an option to insert stochastic inputs if or when a designer is unsure of unpredictable quantities.[315]

When we reached out to Eurac Research, the organization confirmed that their BIPV modeling tool considers surroundings (including surrounding buildings) required as input for the 3D model of the building and surroundings. It is considered in the plane of array irradiance calculation. In terms of accounting for complex shading, the tool places a sensor in the centroid of each module for the calculation of irradiance with the ray-tracing software Radiance (including reflections and near shading caused by the surroundings). Shading is considered uniform at the module level. According to Eurac Research, this assumption was necessary to decrease the computational time required for the irradiance calculation, since their tool focuses on early design optimization. With resect to providing information pertaining to system yield—yes, it does. The tool allows optimizing the system configuration according to target function. At the end of the process, the results are presented as a lifetime economic and energy analysis including thermal losses, degradation losses, and battery aging. When asked if the model includes solar heat gain coefficients and impact on building thermal loading, the response was "not directly"—the tool considers the electric consumption profile as a static input for optimization. However, usually they calculate the consumption profile with a dynamic building simulation software (TRNSYS). Then they optimize the system configuration, and if required, simulate again the building considering the installation of the BIPV system. In that way, they can consider the impact on building thermal load.

7.4.2 BIMSOLAR

The PVSITES project, which has received funding from the European Union's Horizon 2020 research and innovation program, aims to "drive BIPV technology to a large market deployment by demonstrating an ambitious portfolio of building integrated solar technologies and systems, giving a forceful, reliable answer to the market requirements identified by the industrial members of the consortium in their day-to-day activity."[316]

Originally developed by CADCAMation, PVSITES addresses the need for a software tool that can jointly simulate BIPV products and building energy performance through BIMsolar. BIMsolar is a software tool that helps users integrate BAPV or BIPV in the design, construction, and management of their buildings. BIMsolar is a Software as a Service (SaaS) platform that supports every stakeholder involved in the design of a solar building. eCatalogs feed in solar PV simulation with specific BIPV parameters, enhancing visual design and improving both thermal and visual performance. BIPV products can be showcased in a virtual workspace to support the various individuals and entities in the supply chain. The PVSITES software suite is based on the BIMsolar platform. It supports professional and academic users, allowing them to easily model and evaluate BIPV projects in terms of architectural design, energy production, thermal impact, and light transmission.[317]

According to PVSITES, key features of the solution include its ability to import building 3D models, select the location of the project and download corresponding weather data, visualize irradiance on all surfaces of a 3D model, import existing BIPV products into the software, layout BIPV modules and surfaces in various configurations (roofs, façades, canopies, etc.), and precisely simulate PV performance by accounting for losses due to shadowing and other factors, among other features. There is a build-in database of all BIPV products developed within the PVSITES project.[318]

A paper titled "BIM—A Driver for Energy Transition and BIPV Adoption" was written by Van Khai Nguyen and Philippe Alamy, both with CADCAMation at the time of publication, and featured as part of the EuroSun 2018 Conference Proceedings. This paper clarifies the connection between PVSITES and BIMsolar, noting that the PVSITES BIM solution is based on the BIMsolar software and it is a combination of two key innovations: "a standalone BIMsolar software for high performance computing in solar simulation and calculation over imported 3D models"[319] and "a connected web portal aimed at exchanging data (product features) and projects with standalone software, enabling manufacturers to disseminate innovations towards designers from element to building level, in a web to 3D design workflow."[320]

The BIMsolar website states that EnerBIM is the current developer of BIMsolar. EnerBIM is a historical and technological partner for CADCAMation.[321] BIMsolar is the commercial version of the BIPV-Insight software solution, which was developed by a European consortium with EIT-InnoEnergy funding.[322] [323]

In reaching out to EnerBIM for clarification on the BIMsolar tool and its capabilities, the company confirmed that it is suitable for modeling BIPV and BAPV. The tool accounts for surrounding buildings. It simulates the 3D distribution of irradiation (direct, diffuse, reflected) on any 3D scene (3D geometry from urban planning or architecture). The model also accounts for complex shading, including any shading with levels of details (LODs) from the 3D scene (far to close obstacles). BIMsolar also provides information pertaining to system yield. The tool provides array yield (BAPV/BIPV grids of modules) and final yield (AC production, inverter out). With respect to the inclusion of solar heat gain coefficients and impact on building thermal loading, EnerBIM stated that this is in their roadmap, to provide an impact on building envelope as a key exploitable result. The company also noted that BIMsolar generates BIM BIPV and BAPV systems, replicated into native Autodesk REVIT projects, for example. They are also working on linking Energy Modeling (compatibility with EnergyPlus from the Department of Energy) with BIM.

7.4.3 LU-SIM

LuciSun is a Belgium-based company that specializes in advanced consulting, simulation tools, data analytics, and research and development in the solar energy segment. LuciSun has developed LU-Sim, a solar energy simulation tool that offers features such as energy yield assessment, detailed calculations of PV energy losses, and calculation of exceedance probabilities. LU-Sim also enables more complex simulations, such as those involving complex shading scenes, bifacial PV energy gain, and BIPV.[324]

In reaching out to LuciSun, the company confirmed that LU-Sim is suitable for modeling BIPV, it accounts for surrounding buildings and complex shading, and it provides information pertaining to system yield. Regarding the question about the model including solar heat gain coefficients and impact on building thermal loading, it was stated that this is still a bit under development to compliment a new I-V curve algorithm they are working on, using the GPU to parallel computing of the solution. Their solution leverages the GPU capabilities of parallel computing to perform the computation in a fraction of the time, compared to other software tools, with increased resolution and accuracy and a user-friendly 3D interface. This tool can be used to model BIPV projects in the U.S. and around the world, as it includes an algorithm that computes the sun position at any time depending on the latitude and longitude. They also include a web service request to PVGIS to get yearly irradiance values for a given location, though it is possible to include specific irradiance values more accurately from other sources, such as SoDA (or other databases).

7.4.4 PV*SOL

PV*SOL is a professional PV software tool used by planners, architects, installers, and technicians to plan and design efficient PV systems. Solar PV design can be complex and require engineers and architects to account for many factors, including the size and orientation of the system, the number and use time of electrical appliances, climate, sun radiation of the system, local grid distribution, and capacity, among other factors. PV*SOL provides intelligent simulation models of a PV solar system. One of the key features of PV*SOL (and particularly PV*SOL Premium) is that it provides 3D shading analysis. Users can visualize all roof-integrated or mounted systems with up to 5,000 modules in 3D and calculate shading based on 3D objects.[325]

PV*SOL is provided by Valentin Software. According to Valentin Software, PV*SOL can be used to model BIPV. Users can select the installation type "roof integrated" and then the simulation assumes that the PV modules form the roof or façade cladding. The tool does account for surrounding buildings. Using PV*SOL Premium in 3D, users can also define surrounding buildings and objects (such as trees). They will be considered in the shading simulation. In the 3D planning of PV*SOL Premium, complex shading is taken into account. With respect to system yield, the program does simulate the yield of the defined PV system. In response to the question regarding the inclusion of solar heat gain coefficients and impact on building thermal loading, Valentin Software noted that the simulation model takes into account the temperature coefficients of the modules and also a temperature offset, depending on the installation type. However, building thermal loading is not simulated.

7.4.5 PVSYST

PVsyst is a photovoltaic modeling and simulation software that is designed for use by architects, engineers, and researchers. The software system enables a user to specify the desired power or available area, choose the PV module from an internal database, and choose the inverter from an internal database. PVsyst will propose an array and system configuration that will enable users to conduct a preliminary simulation. The software features tools and capabilities to assist in system sizing, 3D shading, grid storage, ageing, energy production simulation (based on location, orientation, and available irradiation), and economic evaluation.[326]

PVsyst SA provided additional information about the PVsyst software tool. According to the company, PVsyst can be used to model BIPV. There is a full 3D editor for the surrounding shadings and a model for the PV module's thermal behavior also in integration. PVsyst accounts for surrounding buildings and complex shading. Regarding shading, users can import drawings from other software such as Sketchup, PVCase, Helios3D, and AutoCAD, among others. The software tools provides information pertaining to system yield—the simulation for the evaluation of the energy yield is really the basic objective of the software. In terms of the inclusion of solar heat gain coefficients and impact on building thermal loading, those capabilities are not currently implemented.

7.4.6 SOLARIUS PV

Solarius PV is a BIM software solution from Acca Software that aids in the technical design and financial analysis of PV systems. The tool features extensive libraries of PV panels, inverters, and batteries and it supports the 3D modeling of parametric PV system objects. Solar irradiance data is acquired from Meteonorm or PVGIS databases. The level of PV shading can be calculated directly from a photo. Solarius PV can be used to model a range of PV systems, but most often it is used for rooftop PV systems, PV systems mounted at the ground-level, and PV systems on parking structures (acting as canopies). With this tool, designers can use 3D objects to quickly model the building's footprint, define the PV field installation surfaces, and account for any obstacles (such as chimneys, roof dormers, and pylons). 3D modeling enables users to model system layout and positioning in real time and throughout the year, according to the actual conditions at an installation site (inclination, orientation, radiation, shading, etc.). Users of Solarius PV can import a project as a BIM model of a building or installation site as an IFC file produced using common BIM authoring software (Edificius, Revit, ArchiCAD, AllPlan, VectorWorks, and others). The PV system can be designed directly on the imported model and then the PV system BIM model can be exported in IFC file format.[327]

Solarius PV can take into account solar shading caused by a variety of long-distance obstacles, such as mountains, hills, buildings, and trees. This can be done through a photographic survey—PV system shading can be calculated directly from a photo. The tool also allows users to check the effects of shading projected on the PV modules by nearby obstacles such as chimneys, walls, and antennas—and users can see how the solar path varies on an hourly, daily, monthly, and annual basis. Using Solarius PV, designers can simply click on the surface where the PV installation is desired and, once the surface has been identified, the software helps to select the correct number of modules based on the design criteria.[328]

Acca Software was contacted for additional product information. According to the company, Solarius PV allows users to model BIPV systems using the building elements, upon which they can define their integrated solar generator. The 3D model of the building, or the equivalent IFC file, must have those supporting surfaces modeled so that the software can provide sizing options. This can be a bit challenging, especially for very large buildings with unusual forms—but it is possible. In terms of accounting for surrounding buildings and complex shading, the solar diagram set up does allow users to define the shading effects produced by surrounding vegetation, buildings, and mountains. The ideal solar irradiation value for a given location is reduced according to the shading factor. Other, more direct, nearby buildings can either be modeled with the generic volume object or brought in via 3D model files or IFCs. In this case, the software will only simulate how the shadows are cast, but no energy losses are taken into account in the current version of Solarius. Solarius PV provides information pertaining to system yield. All financial and technical aspects are taken into account and all charts, tables, and analysis tools allow the user to determine which design solution proves to be more efficient in terms of economic performance metrics. In response to the question on the inclusion of solar heat gain coefficients and impact on building thermal loading, Acca Software noted that Solariius does not perform any building energy model simulations, but their upcoming TerMus PLUS solution (which will be released very soon) allows the user to import the designed solar PV system as an IFC in order to perform a dynamic thermal analysis (internal solver is based on EnergyPLUS). Therefore, it is capable of providing a completely thermal performance analysis for the entire building.

7.4.7 CITYSIM

Researchers at Switzerland's Ecole Polytechnique Fédérale de Lausanne (EPFL) are working on using 3D LiDAR data in urban BIPV modeling and simulation. They developed the CitySim software tool. CitySim is discussed alongside other tools in the 2016 paper, "3D Model for Solar Energy Potential on Buildings from Urban LiDAR Data." CitySim is based on the EPFL's CitySim Solver, but a graphical user interface version of the tool—CitySim Pro (which is free) is provide by Kemco.

In correspondence with Kemco, it was confirmed that CitySim is suitable for modeling BIPV. The tool can define any surface in a scene as a solar panel, including wall surfaces. CitySim also takes into account surrounding buildings and complex shading. The software tool accounts for surrounding buildings for both shortwave radiation shadowing and inter-reflections, as well as for longwave exchanges between building surfaces. With respect to complex shading, CitySim is made for a simulation at the district or city-scale, and therefore can take any type of shading into account (balconies, overhangs, and even more complex shapes). CitySim provides information pertaining to system yield. Users can define for each building in the specific input XML file for CitySim an Energy Conversion System, which can be a simple boiler, a heat pump, a cogeneration system, and a combined cogeneration with heat pump system. Each system can be defined with its efficiency. In response to the question pertaining to the inclusion of solar heat gain coefficients and impact on building thermal loading, their model does include this. For each building surface, one can define a glazing ratio and associated U-value and SHGC (solar heat gain coefficient). The internal solar gains are computed on an hourly basis and impact the thermal load of the buildings.

7.4.8 E-BIM

E-BIM was discussed in a March 2018 paper published in the journal *Automation in Construction*, titled "e-BIM: A BIM-Centric Design and Analysis Software for Building Integrated Photovoltaics." The authors of the paper are affiliated with Zhejiang Sci-Tech

University (in China), Central South University (College of Information Science and Technology, in China), and KU Leuven (ELECTA/ESAT, in Belgium). This research group proposed a uniform BIPV design platform called e-BIM, which is a BIM-centric BIPV design and analysis software platform that seeks to address the related design concerns via one uniform data model. As noted in the article, the current prototype was developed based on Autodesk Revit and has been tested in a practical BIPV application. These tests indicate that this platform achieves seamless BIPV design for architects, PV system designers and electricity professionals, along with an 11.7% cost reduction in the photovoltaic system cost and a 2.95% reduction in transmission losses compared to the initial BIPV design.[329]

In reaching out to the research team with questions about e-BIM, it was confirmed that the tool is, of course, suitable for BIPV modeling and it accounts for surrounding buildings and complex shading. Regarding surrounding buildings—the user would have to provide the model of surrounding buildings. Users could also provide a simplified version of surrounding buildings, as the details only have a slight impact on the final results. Regarding the issue of complex shading, the tool does account for this and users can adjust accuracy by changing the smallest patch for calculation. They can balance between accuracy and speeds with the size of the patch. E-BIM provides information on system yield. There is a tool that allows users to input their cost and yields and it helps them make calculations. In response to the question concerning the inclusion of solar heat gain coefficients and impact on building thermal loading, the model does include this, but the user needs to provide basic information for the calculation. The impact of building thermal loading can be partially calculated with the native model of Revit green calculation. They did not provide that calculation, but it can be integrated. It was also noted that the team had developed a tool to provide the best wiring solution for BIPV panels to minimize the impacts of partial shade on the panels. In addition, they developed support on the power flow calculation to find the best plugin point for the PV source to reduce the power transmission loss.

As a research team developed this tool, they recognize the constraints in continuing its development. It is difficult for a university researcher to continue the development of e-BIM. It has to be upgraded along with the upgrade of Revit. The SDK changes almost with each version of Revit and the plugin system has some limitations. To overcome those limitations, they would need to do the computation away from Revit. There is room for further development here.

7.5 SUMMARY

While much of this report has focused on non-technical challenges and opportunities for BIPV, one technical challenge that remains is modeling, particularly for complex shaded or urban environments. One approach to solving this issue is the use of BIM (Building Information Modeling) which acts as “an intelligent 3D model-based process that provides architecture, engineering, and construction (AEC) professionals the insight and tools to more effectively plan, design, construct, and manage buildings and infrastructure."[330] Presently there are a handful of BIM tools for BIPV modeling on the market, as well as several offerings developed by universities and research institutions. Many of these solutions integrate or draw from existing tools such as Autodesk and MATLAB. This section briefly introduced some of these noteworthy tools and the groups that are developing tools for BIPV modeling and simulation.

8.0 APPENDIX

This section includes a brief overview of PV modeling tools. Modeling and simulation tools that specifically mentioned their use with modeling BIPV projects were profiled in the body of the report. The modeling and simulation tools featured here are broadly applicable to the modeling and simulation of solar PV systems and projects, with a focus on complex projects, features to address shading, and energy yield estimation.

8.1 PV MODELING & SIMULATION TOOLS

System Advisor Model (SAM)

The System Advisor Model (SAM) is a free, open-source techno-economic software model that supports decision-making for those in the renewable energy industry, including project managers and engineers, policy analysts, technology developers, and researchers. SAM can model many different types of renewable energy systems, including a variety of photovoltaic systems, including high concentration PV systems.[331]

RETScreen Expert

RETScreen is a clean energy management software system designed to support energy efficiency, renewable energy, and cogeneration project feasibility analysis, as well as ongoing energy performance analysis. RETScreen Expert is a more advanced version of RETScreen software, which is available to users for free. Using RETScreen, professionals and key decision-makers can quickly identify, assess, and optimize the technical and financial viability of clean energy projects. As a decision intelligence software tool, RETScreen allows managers to measure and verify the performance of their facilities while highlighting additional energy savings and energy production opportunities.[332]

HOMER Pro

HOMER Pro is a microgrid software tool from HOMER Energy. HOMER Pro was originally developed at the National Renewable Energy Laboratory (NREL). Among its functions, HOMER is a simulation model that can simulate a viable system for all possible combinations of equipment considered by project stakeholders. HOMER can simulate hundreds or thousands of systems. The tool supports optimization, exploring all possible combinations of system types in a single run, and then sorting the systems based on the optimization variable of choice. HOMER Pro also enables users to compare thousands of possibilities in one run—looking at the impact of variables and how the optimal system changes with each variation.[333]

PV F-CHART

PV F-CHART is a comprehensive PV system analysis and design program that provides monthly average performance estimates for each hour of the day. The calculations are based on methods that were developed by the University of Wisconsin, which leverage solar radiation usability to account for statistical variations of radiation and load. PV F-

CHART is used with utility interface systems, battery storage systems, and stand-alone systems.[334]

HELIOS 3D

HELIOS 3D is an advanced planning tool for utility scale PV plants. This modeling and simulation tool allows for the shadow-free placement of PV racks on a digital terrain at any geographic position. HELIOS 3D supports accurate shading analysis and it includes a fully-integrated module for yield assessment. Users can compare different layouts and calculate ideal adjustments and module inclination angles by using the simulation tools, which take into account meteorological data and other factors.[335]

Polysun

Polysun refers to a family of software tools from Vela Solaris. Polysun software supports energy system simulation and provides reliable results pertaining to functionality, energy efficiency, and profitability. There are three main Polysun solutions—Polysun Designer, Polysun Standard, and Polysun SPT. Polysun Designer can depict an energy system at the early planning stage and systems can be built up quickly to realize the potential for optimization. This tool combines applications to meet heating, cooling, electricity, and electromobility requirements. Users can choose from more than 150,000 deposited energy system components and the tool supports the simulation of every market-standard technology (worldwide).[336]

Polysun SPT is a tool for designing PV systems. Users can select a roof using Google Maps or upload their own roof plans and aerial photographs. The simulation provides detailed results based on a wide range of data—such as current Meteonorm data, roof orientation, roof shape, interference surfaces, partial shading elements as a result of nearby objects, among other data points. This tool supports the energy and economic analysis of PV systems, providing reliable energy yield forecasts.[337]

INSEL

INSEL is a multifunctional software that has been developed for use by researchers, students, teachers, engineering offices, planners, and operators of renewable energy systems. The Solar Electricity and Solar Thermal Systems libraries contain the models and data for the simulation of PV modules, inverters, and solar thermal components. An algorithm extracts the relevant parameters from manufacturers' data sheets or flasher data to calculate the voltage-current characteristics for all meteorological conditions. This modeling and simulation tool can address yield and how different factors can affect energy production. The tool can also take into account the shading of individual modules.[338]

Auroro

Aurora is a software tool for solar design and sales. Using this modeling and simulation tool, users can model their site, model the electricity load profile, conduct a detailed shading analysis, drag and drop modules and other balance of system components, perform NEC validation, and simulate energy production. When users drag and drop modules, inverters, and other system components in the integrated CAD environment, the Aurora tool will provide real-time feedback on component placement and electrical configurations. The software tool leverages algorithms and runs through thousands of different combinations to help users generate the most cost-effective site designs. Modules and inverters can be selected from an extensive product library. Aurora's product database is consistently updated with the latest products on the market, including smart modules.[339] Aurora's irradiance engine provides accurate solar access values and supports shading analysis for any location, worldwide.[340] In correspondence with Aurora Solar, it was confirmed that this software tool is *not* suitable for BIPV at this time. However, it is suitable for traditional solar, accounting for surrounding buildings, complex shading, and providing information pertaining to system yield. The tool does not include solar heat gain coefficients and impact on building thermal loading.

ArcGIS
ArcGIS features Solar Radiation tools that can enable users to map and analyze the effects of the sun over a particular geographic area for specific time periods. Users can perform solar radiation analysis for a landscape or a specific location. The solar radiation tools in the ArcGIS Spatial Analyst extension enable users to map and analyze the effects of the sun over a particular geographic area and it accounts for atmospheric effects, site latitude and elevation, steepness or slope, compass direction (aspect), daily and seasonal shifts of the sun angle, and the effects of shadows cast by surrounding topography. The outputs can be integrated with other GIS data and can aid in modeling physical and biological processes that are affected by the sun.[341]

Solar Pro
Solar Pro is a PV design software used by solar installers, developers, and engineers. This modeling, simulation, and design tool enables users to visualize shading and accurately configure module coverage. Solar Pro is used to create 3D models of residential, commercial flat-roof, ground-mounted, and single and dual-axis tracker PV systems. The shading effects of each object created in Solar Pro—including trees, buildings, and adjacent PV arrays, among other objects—can be visualized on a minute-by-minute basis and year-round. Solar Pro predicts hourly electricity generation using scientific and industry-standard mathematical models. Solar Pro streamlines PV system design by consolidating 3D CAD layouts, shading analysis, power generation calculations, and reporting. Engineers and designers use Solar Pro for advanced 3D shading analysis, site selection, determining accurate energy calculations, design optimization, system layout, and developing detailed reports.[342]

HelioScope
HelioScope is a web-based design tool for solar professionals available from Folsom Labs. Key features of the tool include 3D design, rapid proposal development, bankable simulations, automatic CAD export, users can model up to 5 MW systems, it features a

library with 45,000 components, global weather coverage, and shade reports, among other features.[343]

PVCAD from PVComplete

PVCAD from PVComplete is a CAD solution specifically for solar, built on Autodesk technology. Users can select design criteria from PVCAD's integrated database, which includes thousands of different inverters, modules, and racking partners. Users also have the option to add their own equipment. PVCAD uses production modeling powered by PVWATTS, which was created by the National Renewable Energy Laboratory (NREL). Data gives hour-by-hour production data over the course of the entire year. The tool leverages the most up-to-date weather data, with global coverage provided by Meteonorm. This modeling and simulation tool supports shadow modeling, energy production modeling, and design comparison.[344]

BlueSol

BlueSol is a software tool for the design of PV systems. The platform features an interactive design and enables the automatic and optimized insertion of strings, inverters, panels, batteries, and cables. Users can edit the arrangement of inserted devices, manage and edit obstacles, account for shading, and obtain estimates related to PV energy production.[345]

Archelios

The Archelios suite of software solutions from Trace Software helps to manage PV projects from design to operation. The software suite includes four offerings: Archelios Pro, Archelios Calc, Archelios Map, and Archelios Ray. This tool is used by research departments and PV installers who design, develop, and maintain many types of PV installations. Archelios Pro is a professional software tool to support the design, calculation, and simulation of a PV project. Leveraging a 3D simulation model, the software displays a precise yield calculation and a complete analysis of the profitability of the PV installation. Archelios Calc is a software tool for the electrical sizing of PV installations. Archelios Map generates solar maps based on 3D modeling and it visualizes a realistic PV installation for each building. This tool also aids in calculating the profitability of each roof or building.[346]

PV_LIB (PVLIB)

The PV_LIB (PVLIB) Toolbox provides a number of functions for simulating the performance of PV energy systems. There are currently two versions—pvlib-python and PVLIB for Matlab—and these versions differ in terms of both structure and content. Both versions of PV_LIB were developed at Sandia National Laboratories, but they both transitioned to being offered as open-source software tools with an active user community.[347]

Solargis Prospecting Tools (iMaps and pvPlanner)

Solargis develops and operates platforms to facilitate access to historical, recent, and forecast data for nearly any location in the world. Their solar resource database has been acknowledged for being accurate and reliable and hundreds of customers around the world have leveraged their PV software applications and web-based solutions to support the construction, evaluation, and management of solar power projects and elements.[348] Solargis provides prospecting tools—notably iMaps and pvPlanner—which provide access to reliable solar yield estimates. Their tools include over 17 solar resource, meteo, and geographic data layers for the estimation of temperature losses, soling and snow losses, and bifacial gain. Their output data is aggregated as annual and monthly averages, with average hourly profiles for each month. The tools feature interactive charts and tables, enabling users to better understand both PV electricity potential and PV performance. Their prospecting solutions take into account far-shading losses. Horizon data with up to 90m resolution is included for each site, which takes far shading losses (such as from nearby hills or mountains) into account for accurate calculations.[349] With respect to map layers, their prospecting tools account for terrain (elevation, slope, and azimuth), population density, land cover, and the ratio of diffuse to global irradiation.[350] The tools can calculate the payback of a solar energy project, ROI, overall savings, and the levelized cost of electricity using a financial calculator for any site and technical configuration.

DDS-CAD PV

Data Design System (DDS) has developed DDS-CAD PV, a tool for planning PV projects. This software tool enables users to plan PV systems for a range of applications. Roof, façade, and ground mounted PV systems can be planned and visualized in both 2D and 3D. The DDS-CAD PV software tool provides detailed assembly plans, a complete bill of materials, string plans, system diagrams, and reports. The system also provides an integrated yield simulation, which is calculated using the Polysun Inside plug-in.[351] In correspondence with Data Design System, it was confirmed that DDS-CAD is not currently capable of performing modeling and simulation for BIPV. It is used for planning more traditional PV projects; however, it does not account for surrounding buildings or complex shading. The tool does provide information pertaining to system yield. DDS-CAD has an integrated add-on from EQUA for colling load, ESBO. With ESBO, users can include the heat gain coefficients, including shading of surrounding buildings.

SolarBIM PV

Mc4Software Italia S.r.l. is the provider of SolarBIM PV, a modeling and simulation tool for PV projects. SolarBIM PV features hourly simulations, which take into account a range of factors that influence PV system productivity—such as "operation temperature time profile modules, in relation to installation type and integration with the building envelope; shading due to the horizon or obstacles; shading, partial or total, mutual parallel horizontal rows, taking into account the real behavior of the strings when shaded, in relation to their respective organizations; instant performance inverter with partial loads; and any tripping of a power inverter and the resulting conversion losses."[352]

Insight Solar Analysis Tool in Revit

Revit, a popular BIM software solution from Autodesk, includes a function that enables users to conduct a solar analysis. Insight Solar Analysis with Revit provides an analysis of solar radiation to help designers and stakeholders track solar energy throughout their design. As a plugin, it provides automated settings for specific study types, as well as options for customization. There are two main analysis types—Solar Energy—Annual PV and Custom. The Solar Energy—Annual PV option provides an annual simulation of PV energy production, whereas the Custom option would be used as a customizable simulation for general solar insolation studies. Insight Solar Analysis with Revit leverages the Perez Solar Model. Users would look at the 3D view of their model and, using the Solar tool, they can select the surfaces for which they would like to visualize results. Users can look at cumulative insolation, average insolation, and peak insolation. The results provide users with an estimate of annual PV energy production, annual energy savings, building energy offset, and payback period.[353]

It appears that there are a few limitations of this tool. Solar Analysis uses surfaces on the model. A surface can be created from standard architectural elements such as walls, roofs, floors, or ceilings (or conceptual masses). However, detailed geometry element types are not supported. Solar Analysis also does not assume any material properties—surfaces are assumed to be either completely opaque or transparent. As a result, "it is not advised to conduct solar analysis on transparent surfaces, like glazing or curtain walls."[354]

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