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Assessing the potential of steel as a substrate for building integrated photovoltaic applications

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HIGHLIGHTS

- Industrial viability of steel substrates for BIPV at production scale analysed.
- State of the art review of the suitability of steel considered.
- Review of competing technologies given.
- Methodical approach for manufacturing cost model for BIPVs.

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ABSTRACT

Government edicts and national time bound policy directives are shaping the drive toward cost effective renewables such as photovoltaics (PV). Building Integrated Photovoltaics (BIPV) has the potential to provide significant energy generation by utilising the existing building infrastructure as a power generator, engendering a transformation shift from traditional energy sources. This research presents an innovative study on the industrial viability of utilising "rough" low carbon steel integrated with an Intermediate Layer (IL) to develop lower cost thin film BIPV products and is compared to existing commercial products. Consideration of the final product cost is given and potential business models to enter the BIPV are identified. The lab scale and upscaling elements of the research support the significant benefits of an approach that extends beyond the use of expensive solar grade steel. A state-of-the-art review of existing steel-based BIPV products is given and used as a benchmark to compare the new products. The results demonstrate that a competitively commercial product is viable and also highlight the strong potential for the adoption of a "rough" steel + IL focused approach to BIPV manufacture and a potential new direction to develop cost efficiencies in an increasingly competitive market.

1. Introduction

The long term aim of the Paris Agreement is to maintain global warming to levels well below 2 °C above pre-industrial levels. This requires a global step change in governmental policy and a radical transition toward renewables. One of the significant components in this migration toward cleaner forms of energy is the greater use of photovoltaics (PV). Government edicts and national policy directives are shaping the drive toward PV and engendering a transformation shift from traditional energy sources [1]. One of the key elements of this transition is the emergence of Building Integrated Photovoltaics (BIPV).

Within the European Union (EU), directive 2010/31/EU [2] states that all buildings occupied by public authorities built after 31st December 2018 should be nearly zero energy rated. The 2010/31/EU directive also states that all other new buildings must be nearly zero rated by 31st December 2020. This means that new buildings must generate their own energy from renewable sources and not be wholly reliant on traditional grid based forms of fossil fuel related energy beyond these dates. Utilising the building infrastructure to host PV based generation via BIPV has the potential to provide an important component of this transition and enable organisations to comply with 2010/31/EU. However, as highlighted by the International Energy Authority (IEA) in their 2017 report titled: *Perspectives for the Energy Transition – Investment Needs for a Low-Carbon Energy System*; to meet the targets of

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the Paris Agreement would require a significant increase in the use of low carbon technologies within the construction sector [3]. The IEA report also highlights the specific challenges of retrofitting within existing housing stock, highlighting that 70% of the existing infrastructure will exist in 2050 and that robust policy intervention is required in many countries to overcome the many barriers [3].

Traditional building products utilised within the construction industry, have ordinarily fulfilled a single function; namely providing a weatherproofing function in the form of a cladding element, roof, or facade in adherence to specific building regulations. The selection of materials is ordinarily based on physical properties, performance and cost as well as design aesthetics. BIPV differs from traditional PV products that are added after construction or modules that are not integral to the building fabric, in that they offer the advantage of providing the conventional building material with PV generation integrated within the product. The definition generally accepted for BIPV, is contextualising the definition by the product's power generation abilities and impact on the building's integrity if the BIPV product was removed. In contrast, traditional rack mounted modules are not integral to the building's infrastructure and can be removed with minimal impact [4,5]. BIPV products are considered a functional part of the building structure, or architecturally integrated into the building's design. This key advantage over traditional non-integrated solutions highlights the potential for the initial costs of the PV element to be either partially or fully offset by reducing the costs for the building materials component of construction as well as installation. These aspects have contributed to studies highlighting BIPV as one of the key elements of the zero energy building EU target for 2020 [6]. The planning and development of multi-function buildings with integrated façade and roof elements, capable of fulfilling energy generation as well as technical and legal demands, could become an essential, accepted part of the architectural mainstream [7] and building design [6]. The retrofit of BIPV within existing building infrastructure, exhibits additional challenges over new build BIPV, but greater potential due to the available existing infrastructure. Designers and architects need to consider building form and function as well as impact of additional loading on the building's structural integrity. However, the potential for retrofit BIPV is significant. Studies have highlighted that building rooftops in the US could potentially accommodate up to 660 GW of installed capacity, a substantial contribution to renewable energy requirements [8]. Many cities around the world have substantial existing infrastructure and could benefit greatly from hosting BIPV products that are able to accommodate the design considerations and characteristics of existing buildings [9,10].

A study from Grand View Research highlights that the global BIPV market is predicted to reach $31.14 billion by 2024, a significant trajectory of growth from the $6.94 billion level in 2015 [11]. Furthermore, the report indicates that thin-film BIPV is expected to witness highest Compound Annual Growth Rate (CAGR) of over 20% from 2016 to 2024 due to superior integration within building envelopes in comparison to crystalline products. The main contributor to these figures is integrated roof systems which account for 61% of the overall revenue for BIPV manufacturers [11].

Thin film BIPV can be layered onto a substrate of only a few μm thick providing a range of applications where the product can be adhered to a variety of building shapes or surfaces. Installation and Balance of System (BoS) costs are reduced for thin film BIPV products [12,13]. Thin film PV can be bonded to building surfaces using peel and stick technology or separate bonding adhesive, negating any requirement for racking infrastructure or structural support. These attributes lend themselves to BIPV applications where the characteristics of new or existing building infrastructure can be accommodated. The stated performance of c-Si based technologies is greater when compared to thin film technologies such as amorphous silicon (a-Si) or Copper Indium Gallium Selenide (CIGS) [14]. However, thin-film solar products can generate energy in sub optimal spectral conditions and are thereby, capable of producing higher relative real world energy yields in comparison with c-Si based systems [15]. Thin film BIPV can be installed within north facing facades or vertical faces where c-Si modules would provide relatively poor performance [16]. Within higher temperature installations, thin-film technologies exhibit greater performance characteristics negating any requirement for additional cooling mechanisms. Thus, thin film PV can avoid the significant drop in performance (up to 50%) of c-Si modules in tropical and hot regions and maintain performance even in low ventilation scenarios [12]. In cases where modern Roll to Roll (R2R) manufacturing techniques and processes are utilised, thin film BIPV products can offer: less waste, minimal handling and reduced shipping costs.

The advent of thin film PV technologies has transformed the potential for BIPV with many forecasters highlighting the high levels of energy demand that could be fulfilled by this technology [17]. However, market conditions within the PV industry including thin film manufacturers, has been problematic. The targeting of global PV markets by the heavily subsidised Chinese manufacturers since 2007/08 has proved to be the catalyst for a prolonged period of difficult trading conditions. Numerous manufacturers have been unable to trade profitably leading to inevitable bankruptcy or reassessment of business models to focus on more downstream activities [18]. The emergence of new technologies and focus on leading edge thin film products has not been an insulator from the problems within the sector. These issues have impacted firms across the spectrum including thin film specialist Hanergy, which was forced to shed 2000 jobs and reported a $1.6 billion loss for the 2015 financial year [19]. These issues highlight the trend of ongoing price competitiveness amongst PV manufacturers with reports highlighting the continued downward pressure on costs continuing to 2020 and beyond [20,21]. The ongoing demand for niche targeted PV technologies such as BIPV is clear, as targets such as directive 2010/31/EU [22] facilitate change within the market and drive demand. Manufacturers will need to focus on efficient production methods and analyse all cost elements within the supply chain to retain competitiveness within the industry. Innovation is critical as the BIPV industry matures and establishes itself from its current niche position.

This study reports the market potential and cost effectiveness of BIPV products utilising low cost steel substrates. This entails a market analysis of the current state of the BIPV and thin-film industry. Furthermore, a component costings and manufacturing feasibility modelling is provided to estimate a realistic cost (€) for a competitor BIPV product manufactured onto steel. The strengths of the potential product, business justification and industrial viability is discussed. Such work is imperative for the product development and novel as it has not previously been conducted; to implement such production lines requires multi-million pound investment and careful evaluation is required from early steps in the manufacturing process.

The remainder of this paper is structured as follows: Section 2 outlines the background and aims of the study, Section 3 reviews the relevant BIPV related literature and key aspects of the BIPV market sector and shows how steel based products could compete. Section 4 defines the methodology and process utilised within the cost study to derive the required data. Section 5 shows the results of the product cost model and manufacturing feasibility to arrive at a realistic cost (€) for a competitive BIPV product. Section 6 develops the industrial viability theme in the context of the BIPV market place. The key findings and suggestions for future research are outlined in the Conclusions section. To our knowledge, this is the first extensive study of cost analysis of steel-based PV products with an auditable comparison to state of the art products.

2. Study aims and objectives

The main objective of this study is to ascertain the industrial viability of innovative approaches to the design and manufacture of BIPV products utilising low cost steel substrates and an 'Intermediate layer'