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# A cost roadmap for silicon heterojunction solar cells

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ABSTRACT

Research and development of silicon heterojunction (SHJ) solar cells has seen a marked increase since the recent expiry of core patents describing SHJ technology. SHJ solar cells are expected to offer various cost benefits compared to conventional crystalline silicon solar cells. This paper analyses the production costs associated with five different SHJ cell designs, including an interdigitated back-contacted (IBC) design. Using life-cycle costing, we analyzed the current cost breakdown of these SHJ designs, and compared them to conventional diffused junction monocrystalline silicon modules. Coupling the results for current designs with literature data on technological improvements, we also present a prospective analysis of production costs for the five SHJ cells and modules.

For current designs, module costs were calculated to be 0.48–0.56 USD per Watt-peak ($W_p$) for SHJ modules, compared to 0.50 USD/$W_p$ for a conventional c-Si module. The efficiency bonus for SHJ modules compared to conventional c-Si modules is offset by a strong increase in metallization costs for SHJ designs, as comparatively large amounts of low-temperature silver-paste are required. For module materials, the requirement for conductive adhesives results in a small cost penalty for SHJ modules compared to c-Si modules, which is more than balanced by the effect of higher efficiency in SHJ modules.

Our prospective study showed that improvements in cell processing and module design could result in a significant drop in production costs for all module types studied. The SHJ modules gain much advantage by reducing and replacing silver consumption, increased cell efficiency and thinner wafers and have prospective production costs of 0.29–0.35 USD/$W_p$. Conventional c-Si module cost is less sensitive to silver paste consumption, limiting the potential for cost reduction, and has prospective production costs of 0.33 USD/$W_p$. Replacement of indium-tin-oxide was not found to contribute substantially to a reduction in module costs.



## 1. Introduction

Concurrently with the strong growth in PV module production and sales, average PV module prices have dropped sharply over the last decade. Polysilicon, wafer, cell and module prices dropped especially sharp over the last few years, as shown in Fig. 1. In the Netherlands, PV module prices including tax dropped by almost 50% between 2011 and 2013, from 2 EUR per $W_p$ to 1.13 EUR per $W_p$ [1], while global spot prices (excluding tax) for PV modules have dropped to 0.6 USD/$W_p$ (see Fig. 1). Price decreases have long been following a learning curve that has been valid for multiple decades, however, more recently, due to decreased demand and resulting oversupply, prices have dropped below what could be extrapolated from the learning curve. As a result, PV producers are scrambling for opportunities to reduce production costs. On the other hand, although residential grid parity has been reached in several countries worldwide [2], PV electricity is as of yet not competitive with fossil electricity generation [3–7]. These two factors emphasize the need for further cost reductions in the PV industry, in order to assure PV production that is financially sustainable and competitive with bulk electricity generation.

Photovoltaic systems offer us the possibility to produce electricity with low emissions of greenhouse gasses [9–13], low energy pay-back time, and low emissions of toxic or otherwise harmful substances, compared to traditional forms of electricity production. Its' modular nature allows for the application on a variety of scales, from small-scale decentralized and off-grid to large-scale, centralized electricity production. According to International Energy Agency's World Energy Outlook, PV will contribute significantly to a sustainable energy supply system [14]. Because of this expectation, adoption of PV is being supported by national

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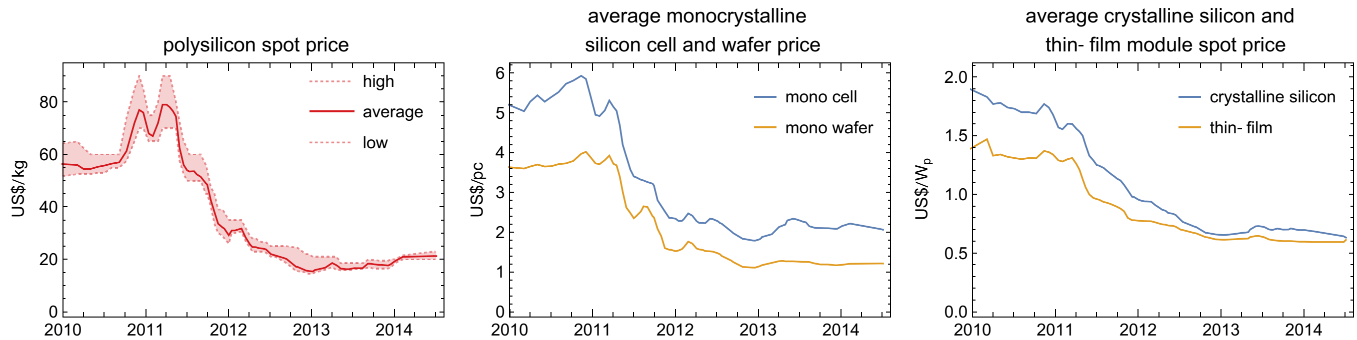


**Fig. 1.** Overview of development of prices for polysilicon (left, in USD/kg), monocrystalline cells and wafers (middle, USD/$W_p$) and crystalline silicon and thin film modules (right, USD/$W_p$). Data: [8].

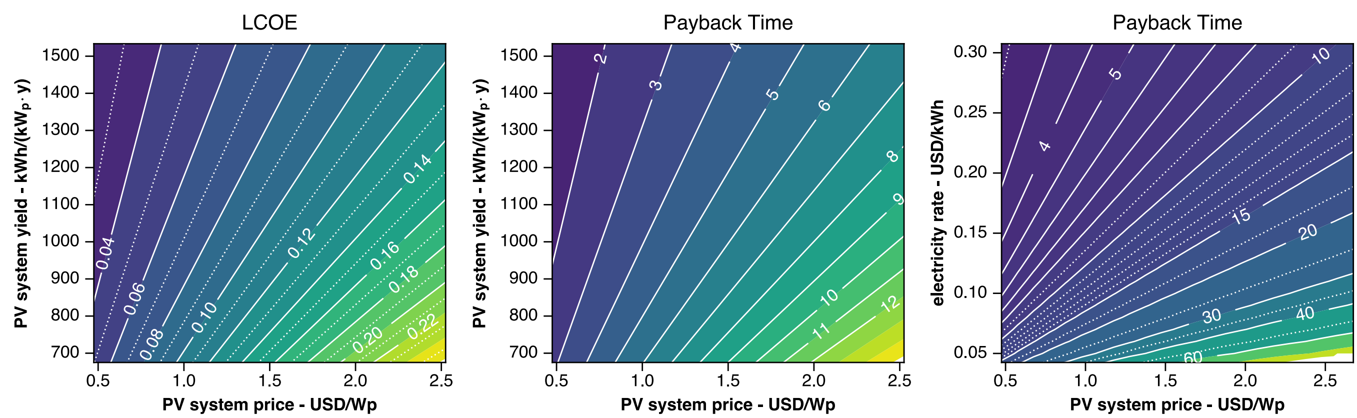


**Fig. 2.** Left: effect of PV system price and PV system yield on the levelised cost of electricity from a PV system. Middle: effect of PV system price and PV system annual yield on the investment payback time of a PV system, based on an electricity rate of 0.26 USD/kWh. Right: effect of PV system price and electricity price on the payback-time of a PV system, at a yield of 875 kWh/k $W_p$.

governments worldwide, at sometimes high financial costs for society [15]. Cost reductions are thus of substantial societal importance when deployment of solar energy covers larger shares of total electricity generation.

In order for PV to become a competitive source of electricity production, the levelized cost of electricity (LCOE) from PV should decrease below residential electricity prices ("socket parity") and below wholesale electricity prices ("grid parity"). Furthermore, for PV to become a viable investment option for both consumers and businesses, the payback time (PBT) of investing in PV should drop to about 3–5 years [16]. Fig. 2 shows the effect of PV system price and annual yield on LCOE and PBT. From this figure, we can deduce that, in order for PV to reach grid parity (instead of the already achieved socket parity) PV system prices still need to drop significantly. For PV to compete with combined-cycle natural gas and coal with a levelized cost of electricity (LCOE) of about 0.05 USD/kWh [17], we estimate that PV system prices need to drop below 0.60–1.00 USD/$W_p$, thus PV module prices should drop below 0.3–0.5 USD $W_p$[1]

For a large part, cost reductions in PV production have been achieved due to economies of scale, and technological learning in the PV production supply chain [18]. More recently we have seen an increased focus on intrinsic cost reductions. General approaches for cost reductions have traditionally been to decrease material use or replace expensive materials with cheaper ones. For instance, silicon consumption per watt-peak ($W_p$) has decreased significantly due to increased efficiencies and the use of increasingly thin wafers, while silver use for metallization has also decreased over the years. Significant cost reductions have been obtained with this approach, however, more recently the room for further improvement has decreased. This has resulted in a variety of approaches being researched, including a shift from the traditional diffused junction crystalline PV devices, towards alternative designs or technologies.

One of those "new" technologies is the silicon heterojunction (SHJ) solar cell technology. SHJ solar cells are produced from silicon wafers in a low temperature process that does not exceed 200 °C. High temperature diffusion of the p-n junction is replaced with a low temperature deposition of a p-doped amorphous silicon layer on an n-type monocrystalline silicon wafer.

This technology is only produced on a large scale by Panasonic (by acquiring Sanyo), but a recent expiry of the core patents describing their SHJ technology has lead to a marked increase in R&D on this technology [19,20]. The large interest is mainly due to the fact that [19,20]: (**1**) SHJ fabrication is a simple process with high efficiency cells as a result; (**2**) the deposition of the thin film layers for SHJ cells can benefit from ample experience with these processes in the flat-display industry; (**3**) SHJ modules have a low temperature coefficient which leads to higher energy yields compared to conventional c-Si modules, and (**4**) SHJ cells benefit more from the application of thinner wafers, because the deposited thin-film layers allow for very good passivation of the wafer surface.

Current R&D mainly focuses on improving device performance, but novel design structures and processing steps are also being investigated, aiming to lower production costs. Examples are

[1] Assuming a PV system yield of 800–1400 kWh/(k $W_p$ year) and a module-to-system price ratio of 2.