# Vertical integrated PV production for an independent and speedy energy transition

Fırat Es[1], Güven Korkmaz[1], Kübra Çelen[1], Özlem Coşkun[1], Joris Libal[2] & Radovan Kopecek[2]

[1]Kalyon PV Research and Development Center, Kalyon Gunes Teknolojileri Uretim A.S., Ankara, Turkey; [2]ISC Konstanz, Konstanz, Germany

## Abstract

PV energy production is becoming more widespread in all societies as a result of the decreasing price of PV systems due to technological improvements in PV cell and module production. Kalyon PV, located in Ankara, Turkey, is a special type of PV producer because of its implementation, under one roof, of vertical integration manufacturing outside of China, from ingot processing to module fabrication. Furthermore, Kalyon PV is more accessible to European countries than Asian PV producers, which is essential these days with the high cost of transportation and the risk of shipment delays. A vertically integrated factory concept, consisting of ingot, wafer, cell and module production, allows changes to be made to production lines, as well as adaptations to innovations in solar cell structures, in order to keep up with market trends more easily. Not only that, production under one roof contributes significantly to reducing production cost by eliminating some sub-steps, such as transportation. In this paper, all the steps in Kalyon PV's vertical production are described, and a cost of ownership (COO) analysis is performed for passivated emitter rear contact (PERC) and advanced cell concepts.

## Introduction

Nowadays, with a growing population and an increase in technological advancements, supplying enough energy to meet demand is vitally important to humankind. Up until now, fossil fuels, such as gas, oil and coal, have been the primary source of energy; in 2020, 65% of electricity production around the world depended on fossil fuels [1]. The problem here is that fossil fuels do not regenerate over a short time period, and even more of a worry is that the process of energy production using these sources is causing damage to nature, which in turn is leading to an increase in global warming effects. Additionally, the dependency on foreign sources of fossil fuels for energy production poses a strategic risk for the countries involved.

Renewable energy resources are gradually coming to the fore as an important solution to foreign dependency on energy, maintaining the balance between economic development, environment and sustainability, energy efficiency and especially energy supply security, and providing significant gains in all these issues. Renewable energy sources make a significant contribution to the economic development of a country by ensuring that the required energy is available continuously and at an affordable price.

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Solar energy is a renewable energy source that has great potential for ensuring the demand for energy is met. It is clear that among renewable energy sources, solar energy is the most promising and trustworthy energy source for the great majority of countries. Solar systems have been used to produce heat and electricity generation for several decades now. PV systems which convert solar energy to electricity directly have been the focus of scientific studies for a long time, and PV systems have become commercially available and more and more feasible during the last two decades. In March 2022, the total installed power capacity of PV systems reached 1TW worldwide [2]. The rate at which PV system capacity is increasing is growing in line with technological developments. Related to these improvements, it is estimated that the newly added power capacity of PV systems per year will reach 1TW until the year 2030.

Today's PV module systems that are being used to generate electricity show differences depending on the cell technology, such as passivated emitter rear contact (PERC), interdigitated back contact (IBC) and passivated emitter rear totally diffused (PERT). PERC, which is based on p-type Si, is one of the most universal technologies among the PV solar cell types, because the production methods, which have been developed over many years, are cost effective. With prices of around €0.2/Wp for bifacial PERC modules, PV has been the 'king of energy' [3] since 2020; the lowest bid for a levelized cost of electricity (LCOE) below €0.01/kWh [4] was achieved in Saudi Arabia.

The market recently began to be dominated by limited supply rather than by demand, and it was not long before PV entered a poly-Si crisis, similar to the one in 2005, but at a completely different capacity level. In addition, the Covid 19 crisis, with some production interruptions, even shutdowns, and a tenfold increase in transportation costs from China, changed the PV market completely.

**Figure 1. Kalyon Karapınar – 1GW bifacial horizontal single-axis tracker (HSAT) solar power plant in Konya, Turkey.**

> "Kalyon PV produces PV modules at a vertically integrated factory, meaning that the production of monocrystalline silicon through to the fabrication of modules is all done under the same roof."

Already at the end of 2021, at Intersolar in Munich in October, the change in mentality of EU's energy performance certificates (EPCs) and distributers became very apparent. The hike in module prices from China of well over €0.20/Wp at that time, as well as the lack of availability of these modules for import, prompted PV system companies to show increased interest in locally produced modules.

The huge ambitions of various EU member states, such as Germany, to install 200GW of PV systems through to 2030 [5] increased the hunger for modules and the desire for security of a stable supply. Since China has a target to set up 80GW of PV systems in 2022, the US 70GW and the EU 70GW as well, a severe shortage of modules and other components is expected in the coming years.

The last straw that broke the camel's back was the start of the war in Ukraine on February 22, 2022. At a historical meeting of the German Bundestag on Sunday, February 27, 2022, it was declared that renewable energies are 'freedom energies' [6] and their deployment needs to be even more accelerated. Finally, as a consequence, since the EU wants to gain independence from gas imports from Russia, as well as from other energy imports, on March 31, 2022, Kadri Simson, the EU Commissioner for Energy, announced that the EU will do "whatever it takes" to bring back PV production to the EU [7]. By that is understood 'vertical production', starting from ingot through to module, including the supply chain of poly-Si, glass and other necessary components. At the moment, the EU Commission and member states, such as Germany and France, are in discussion with PV networks, such as ESMC, SPE, ETIP and EUREC, to understand what will be needed to set PV production up with the necessary 'critical mass' for


**Figure 2. Kalyon PV vertically integrated c-Si PV factory in Ankara, Turkey**

it to become cost effective and sustainable. ESMC has prepared a list for this very purpose [8], and in May 2022, the EU Commission and several member states will announce the outcome. The future for large 50–70GW vertical PV production facilities in the EU looks bright.

Those countries that are aware of the promising future of PV systems have begun studies to encourage the set-up of renewable energy production systems. The Turkish government, an advocate of the widespread use of renewable energy sources for electricity generation, launched a new project to support the PV sector, which is becoming increasingly important among renewable energy sources. Within the scope of this project, a tender process was initiated for the installation of a solar PV power plant in Karapınar in Konya, Turkey, which is a desert-type region not suitable for agriculture. The solar power plant is expected to extend over an area of approximately 19.2km$^2$ at final completion of the installation (Fig. 1).

Kalyon started its vertical integration activities when the Turkish Government initiated its study regarding renewable energy resources, and put in the winning bid for the tender; permission was obtained by a partner to sell the electricity produced from the power plant. After finalizing the necessary tenders and contracts, Kalyon PV started production of PV modules for the Karapınar solar power plant.

Kalyon PV, established in Ankara, Turkey, which is located between Asia and Europe, produces PV modules at a vertically integrated factory (Fig. 2), meaning that the production of monocrystalline silicon through to the fabrication of modules is all done under the same roof. At the Kalyon site, there are four factories, consisting of ingot, wafer, cell and module production lines, supported by an R&D centre located within the integrated plant. The company, which began producing modules for Karapınar in August 2020, increased its G1 production (from ingot to module) to 500MW per year in a very short time. Since the beginning of 2022, it has increased its M10 cell and module production capacity to 500MW and is expected to reach a total annual production capacity of 1GW.

The manufacturing process begins with monocrystalline silicon ingot production from polycrystalline silicon in the first factory containing the ingot production line, and ends with module production in the last factory. Thanks to on-site production, the total manufacturing flow duration is shorter, while the transfer process between intermediate steps is eliminated. On top of these benefits, the integrated factory concept adopted by Kalyon PV also makes it possible and easier to keep up with new technological advances in the solar cell field. Kalyon PV's R&D centre activities carried out on the ingot, wafer, cell and module lines are based around production optimization and improvement, cost reduction and high-efficiency production studies.

## First factory: ingot production line

For the production of monocrystalline ingots from 9N pure polycrystalline silicon, 72 Czochralski (CZ) furnaces are used (Figs. 3 and 4).

The fact that ingots used in wafer production have been produced directly in the factory on site brings the flexibility of producing wafers of various sizes and types. By optimizing the production parameters – pulling rate, temperature, rotating rates, etc. – the furnaces used in ingot production are also suitable for pulling ingots of different diameters. Controlling the doping process in ingot


**Figure 3. Ingot factory at the Kalyon PV integrated facility.**

**Figure 4. Poly-Si to ingot growth using the CZ technique.**

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production also enables the production of solar cells of different technologies.

Detailed investigations of creating ingots with Ga dopants for preventing light-induced degradation (LID) effects in PV modules, and n-type ingot production studies for future technologies, such as IBC solar cells, are ongoing in parallel with mass production. Since ingot production is carried out in the integrated factory, the facility can easily adapt to changing trends in cell size and type, depending on the extendable capacity of the ingot production line, with 24 free areas for furnace assembly.

Kalyon PV can supply ingots of size G1 and M10 in mass production. At the beginning of ingot production, B-doped p-type G1-sized ingots were produced, but today M10-sized ingot production is ramping up. As part of the R&D studies, Ga-, P-, and B-doped ingots of various types are produced on a large scale. Additionally, the diameters of the produced ingots can be modified from G1 to M6 sizes by changing the furnace variables. The created ingots are analysed to ensure they are of sufficient high quality for wafer production. According to the quality test results, ingot cutting steps are scheduled in order to eliminate the low-quality parts of the ingots.

## Second factory: wafer production line

The wafer-slicing process includes two sub-steps, namely cutting ingots into bricks and slicing bricks into wafers. First, ingots that have passed the quality control tests are transferred to the wafer production line for cutting into bricks of equal length, which are then cropped to obtain a square section based on desired cell dimension. Second, the bricks are sliced into wafers, with their thickness being controlled by adjusting the distance between the diamond-coated cutting wires.

The ingot and R&D departments are working on increasing the wafer production yield and structural quality of the wafers, and decreasing the kerf loss during the wafer-slicing process. The produced wafers are classified depending on wafer quality tests, such as lifetime measurement, thickness control and total thickness variation (TTV). After these classifications, the wafers which demonstrate the best qualities are dispatched to the cell production line.

**Figure 5. Clean room for bifacial mono-perc production (G1 line).**

## Third factory: cell production line

High-quality wafers from the second factory arrive at the cell production line for transformation into solar cells. Kalyon PV's cell factory consists of two mass-production lines, one for G1-sized bifacial PERC solar cells and the other for M10 versions. G1 solar cells with a minimum 22% efficiency and 70% bifaciality are being mass produced on the production line, with a daily throughput of more than 300,000 cells (Fig. 5).

The cell production line and the R&D departments have been studying ways to improve the efficiency, bifaciality, stability and lifetime of PERC solar cells. In addition to the performance

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**Figure 6. Quality inspection after the stringing process in the module factory.**

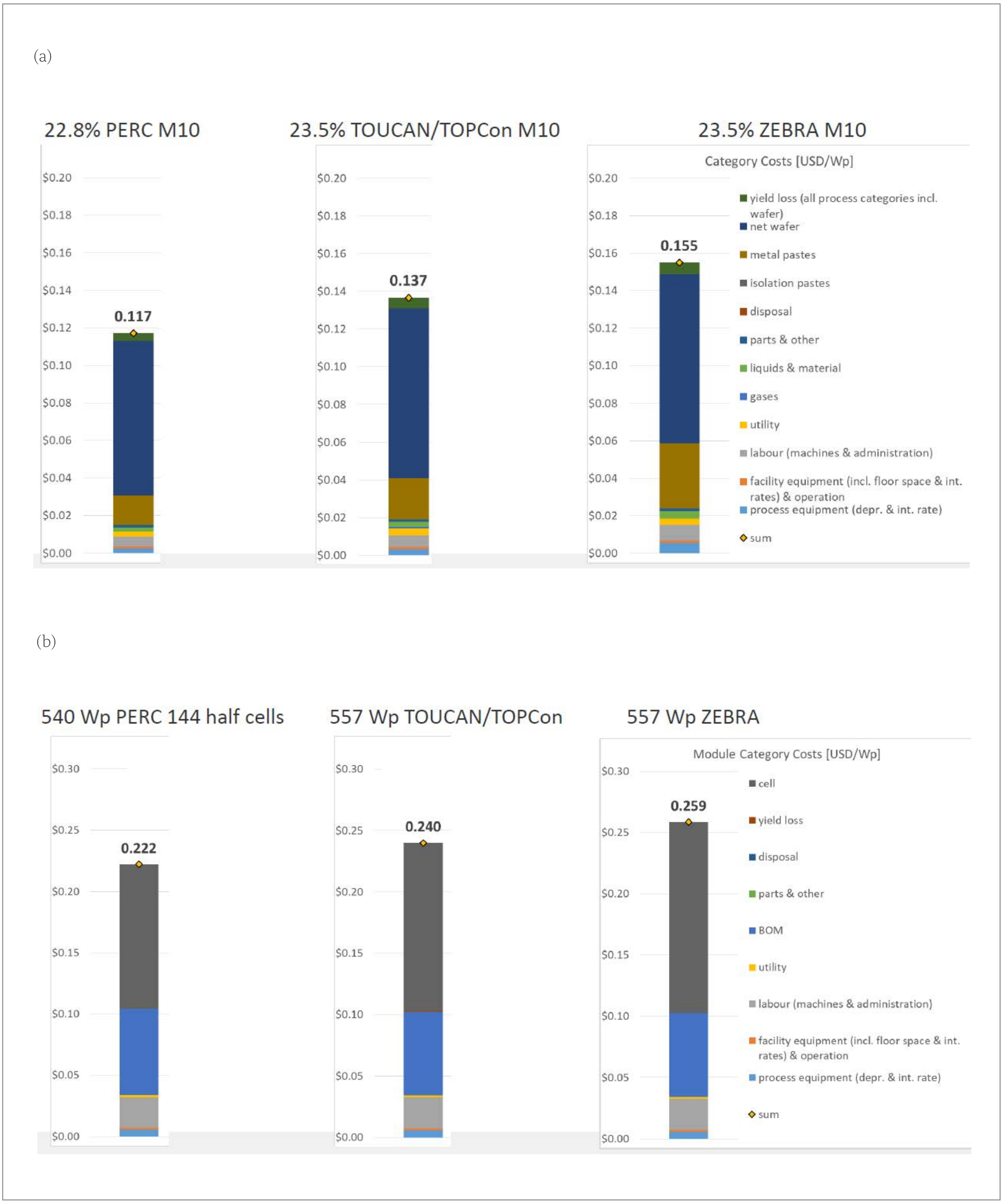


**Figure 7. COO of PERC, TOPCon and low-cost IBC cells (a) and corresponding modules (b).**

enhancement projects, cell production cost-reduction studies, such as decreasing the amount of Ag paste used, are managed. The R&D department has also been collaborating with national and international companies and institutes to keep up to date with new market trends in the solar cell field.

## Fourth factory: module production line

Cells are subjected to a very rigorous quality control process after production and are divided into more than a hundred bins, depending on many factors, such as electrical parameters and colour. Cells displaying the same characteristics are transferred to the module section in one batch, thus ensuring that each module consists of matching cells. Kalyon PV modules are fabricated from 144 half-cells using half-cut solar cell technology (Fig. 6).

Glass–glass and glass–transparent backsheet modules, with and without aluminium frames, are constructed from G1 and M10 cells. Up until the lamination stage, the modules go through very meticulous electroluminescence (EL), *I–V* and visual checks, because there is no turning back after lamination. After the lamination phase is completed, the modules that pass a detailed characterization are packaged and sent to solar panel plants.

The R&D department, along with the module production department, is undertaking projects to investigate ways to increase the lifetime and power of the modules while also improving their stability. Besides these studies, the R&D department also manages sub-projects that include trials of new materials, such as backsheet, glass, frame and encapsulant, ordered from other companies, in order to develop the range of products. The R&D team is also conducting preliminary studies on flexible module structures that can be assembled on surfaces having different slopes.

The Kalyon PV integrated factory is endeavouring to invest in the industry 4.0 concept through different strategies. All the production parameters and measurement results at every stage, from ingot processing to module fabrication, are recorded by manufacturing execution system (MES) databases, whereby instant monitoring of the production can be carried out. Moreover, several research projects using big data analysis are under way; the data related to the production is continuously analysed using statistical methods, and production, quality and yield estimations are conducted. Additionally, a supervisory control and data acquisition (SCADA) centre, designed to cover all four factories, is currently at the installation stage, and will allow remote control of the production chain. The operating status, efficiency and product features of the systems will be controlled from the centre, and interventions can be made if necessary.

The value chain of Kalyon PV starts with ingot poly-Si and ends with module production. The PV module cost depends on lots of parameters, and the integrated factory concept also incurs many expenses. Depending on the reduced production cost, there is no doubt that, because of its rapid adaptation to new technologies, as well as the easy transportation due to its geographical location, Kalyon PV is showing itself to be a promising supplier for the EU solar market.

## COO of PV production outside of China

The cost of PV production today is heavily dependent on the poly-Si price, which is still going up during the poly-Si crisis but that should abate by the end of 2022. The transportation costs from China are still at €0.03–0.04/Wp (container price of €15k), and experts believe that they will remain at least €0.02/Wp. Even though PERC solar cells are approaching their limit with regard to efficiency, the technology's cost of ownership (COO) can still be reduced through economy of scale and enhanced productivity (faster throughput and increased yield). It is believed that the M10 format will be the winner in terms of size for several reasons, mostly because of the optimum packing properties of modules consisting of M10-sized cells in containers.

Fig. 7 summarizes the COO for three different technologies for a 5GW production in the EU and a future silicon poly-Si price of €14/kg and a silver paste price of €650/kg (PERC: 170mg/cell; TOPCon: 260mg/cell; IBC: 265mg/cell).

The COO for all cells still depends mainly on the wafer and metal paste cost, but, even for the EU, the module costs can reach values of €0.22–0.26/Wp for all three of the most prominent standard high-temperature technologies. PERC will continue to dominate in the next five years; however, in the future, n-type technologies will start to gain a significant market share, as their efficiency potential has not yet been reached and because n-type has also several advantages in terms of lower degradation and lower temperature coefficient. With its ability to control the entire production chain, Kalyon PV is also considering upgrading the G1 cell and module lines to a high-efficiency n-type facility to meet the needs of the European and US residential rooftop markets. Studies are ongoing for the feasibility of such an upgrade at the beginning of 2023.

As the largest bifacial PV manufacturer in Europe, Kalyon PV invites readers to the bifiPV 2022 workshop to be held at Kalyon at the end of 2022 and share in the latest developments in bifacial PV technology, and to visit its vertical integrated factory for bifacial PERC technology.

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## About the Authors

Dr. Fırat Es is an R&D manager and currently the head of the R&D Center at the Kalyon PV integrated production factory. After completing his undergraduate and graduate education in the physics department at METU, he went on to receive his Ph.D. in the micro and nanotechnology department. He has 13 years of experience in the field of crystalline silicon semiconductors and PV, and played leading roles in the installation stages of METU GÜNAM PV's clean room and PV pilot production line (GPVL), and Kalyon PV's integrated factory.

Dr. Güven Korkmaz joined Kalyon PV in June 2020 as an R&D researcher, and is currently an ingot, wafer and cell production supervisor at the R&D Center. He received his B.S. in 2006, and his master's in 2010 in physics from Anadolu University. He completed his Ph.D. studies on the growth of GaAs/AlGaAs quantum well structures via the MBE system and the optoelectronic characterizations of these structures, which were used for THz detection in 2017 at Anadolu University.

Kübra Çelen graduated from Bursa Technical University in metallurgical and materials engineering. She received her master's from Hacettepe University in nanotechnology and nanomedicine. During her master's studies, she was a member of the Superconductivity and Nanotechnology Research Laboratory at Hacettepe University and worked on alternative absorber layer materials for thin-film solar cells via vacuum systems. She has been an R&D engineer at Kalyon PV since February 2022.

Özlem Coşkun received her bachelor's degree in metallurgical and materials engineering from Gazi University and her master's in micro- and nanotechnology from TOBB University of Economics and Technology. For her master's, she studied improvements to electron- and hole-transport layers for tandem perovskite photo-electrochemical solar cells. She was also a group member of the Laboratory of Energy Research and worked on thin-film solar cells. She joined Kalyon PV as an R&D Engineer in February 2022.

Dr. Radovan Kopecek obtained his Diploma in physics at the University of Stuttgart in 1998. He also studied at Portland State University (Oregon, USA), where he obtained a master's in 1995. In 2002 he finalized his Ph.D. dissertation at the University of Konstanz and was a group leader there until the end of 2006. One of the founders of ISC Konstanz, he has been working at the institute as a full-time manager and researcher since 2007 and is currently the head of the Advanced Solar Cells department.

Dr. Joris Libal received his Diploma in physics from the University of Tübingen, and his Ph.D. on the topic of n-type crystalline silicon solar cells from the University of Konstanz. He has been involved in R&D along the entire value chain of crystalline silicon PV in the past, and joined the ISC in 2012. He is currently an R&D project manager, working on technology transfer and cost calculations in the areas of high-efficiency n-type solar cells and innovative module technology, as well as on ISC's activities in energy yield simulations.

## Enquiries

Fırat Es
Research and Development Center
Kalyon Gunes Teknolojileri Uretim A.S.
06909 Ankara, Turkey

Tel: +90 444 6 559 (444 6 KLY)
Email: fes@kalyonpv.com
Website: www.kalyonpv.com