# Intellectual property and the next generation of solar technology

As solar technology continues to drive the expanding renewable energy sector, analysis of the patent landscape reveals both the leading players and where the next generation of technology is coming from

By Bruce Rubinger, Cassie Daddario and Sung Hei Yau

Solar energy is a key enabling technology that can help to mitigate the effects of climate change and accelerate the growth of renewable energy. With solar efficiency increasing, solar energy is expected to supply 50% of the world's energy capacity in the next 25 years. Thus, a worldwide race is on to create the innovations needed to power this transformation and capture the benefits with strong patents. However, solar technology faces stiff performance, cost and durability challenges. In this tough environment, companies with a strong IP position covering critical solar technology will emerge as big winners.

IP assets provide a detailed window into the innovative strategies of various solar technology players and enable us to identify the most promising technologies. Global Prior Art's multidisciplinary team – with expertise in photovoltaics, materials technology and IP strategy – has analysed more than 8,500 unique patent families in this complex space, in order to capture the primary focus and positioning of key patent holders and to examine the potential of advanced solar technology to significantly influence the future energy supply and lessen the effects of climate change.

## Solar photovoltaics overview – the basics and challenges

Solar cells that are exposed to sunlight convert solar energy into direct current. Over the past 20 years, the cost of generating electric power from solar – measured in cost per watt (W) – has declined significantly. The worldwide use of solar now exceeds 100 gigawatts, with solar energy now considered one of the greenest forms of alternative energy and a critical technology to address climate change. As a result, advanced solar technology is being pursued worldwide by a range of companies and research institutes.

Solar photovoltaics (PV) are organised into four generations of technology (Figure 1). Based on silicon and supplying 90% of the current solar cell market, Generation 1 (Gen 1) PV is dominant; it offers the advantage of lower cost per watt and relies on readily available materials. The cost of Gen 1 PV has fallen continuously since the establishment of large-scale production, moving from $7.24/W in 2010 to $2.80/W in 2017 (per watt DC, in the residential sector). At present, most of these solar cells are supplied from China (66%). The US Department of Energy (DOE) SunShot initiative has set the ambitious goal of lowering the cost to $0.04/W by 2030, which will require the development of new materials for the next generation of solar cells. However, the wide take up of Gen 1 PV faces several hurdles, including silicon tetrachloride – the highly toxic byproduct created during the production of silicon tetrachloride - the highly toxic byproduct created during

**FIGURE 1.** Traditional and emerging PV technologies

Traditional PV technology

Emerging PV technology

**Generation 1**
Traditional silicon-based cell
- Cheap and readily available
- No material improvement since 2009
- Energy intensive
- Highly toxic byproducts

**Generation 2**
Thin film PV such as CdTe
- Does not rely on silicon technology
- Commercially available
- Toxic material with disposal concerns

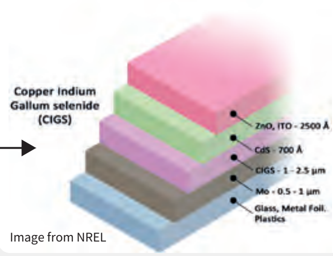
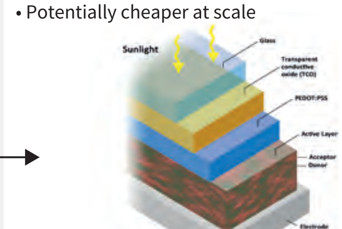


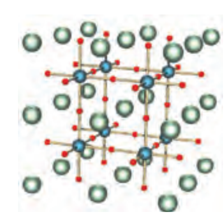

Image from NREL

**Generation 3**
Engineered materials such as dye-sensitised PV or organic polymer systems
- Lower efficiency (for now)
- Environmentally friendly
- Wide range of application surfaces
- Potentially cheaper at scale




Organic PV, image from NREL

**Generation 4**
Nanomaterials or nanoarchitecture systems
- High efficiency with large potential for optimisation
- Environmental and stability concerns
- Laboratory stage materials



1975 | 1990 | 2010 onwards

the production of silicon wafers and the large amount of energy required during production.

Generation 2 (Gen 2) are thin-film PV based on Gen 1 silicon technology, which are produced without the use of labour-intensive silicon wafers. Gen 2 is cost effective, achieving the commercial milestone of $1/W back in 2009. However, Gen 2 PV contains highly toxic metals such as cadmium, making disposal a major concern and slowing mass adoption. At present, the market share for Gen 2 PV is only about 10%.

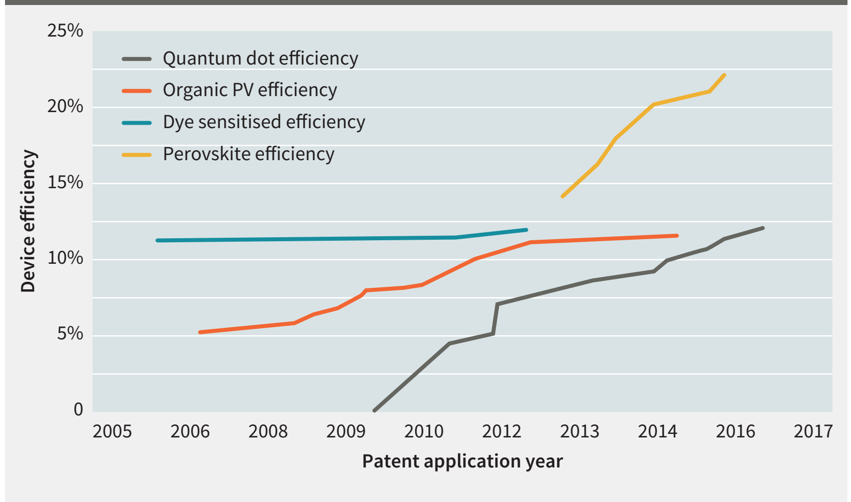
Generation 3 (Gen 3) PV focuses on material design to enhance performance (through the optimisation of donor and acceptor physics). There are currently two major types of Gen 3 PV: dye-sensitised solar cells (DSSCs) and organic photovoltaics (OPVs). OPVs are polymer-based technology, made from common and abundant materials, and are thus more environmentally friendly. OPVs also allows for several low-cost production benefits, including the use of thin-film printing techniques (eg, spin coating and roll-to-roll printing) and do not require the use of expensive clean-room facilities. OPV research began in 1986 and a certified efficiency of 12.6% has since been achieved by the University of California Los Angeles. At present, OPVs are more expensive than Gen 1 and Gen 2 PV and work best for high-cost niche applications (eg, curved surfaces). However, as the market for Gen 3 expands, the cost will fall. A critical commercial milestone would be the ability to achieve production panels with efficiencies of at least 15%, at a cost comparable to or lower than traditional PV.

Generation 4 (Gen 4) PV uses nanomaterials or nano-architectures to offer impressive gains in both efficiency and lowered cost. Two PV technologies have captured the attention of the solar community: perovskites solar cells (PVSC) and quantum dots solar cells. Perovskites are considered to be more promising for commercial solar energy applications. The earliest report of perovskites in photovoltaic applications was in 2009. By 2016, PVSC had achieved a 23% certified efficiency, exceeding current commercially silicon-based systems. In addition, Gen 4 can be adopted to a high-performance tandem cell design, which demonstrates efficiencies nearing 30%. However, the mass adoption of Gen 4 PV faces a number of hurdles and these challenges are the focus of development worldwide. Current PVSC solar cells experience long-term stability problems as well as environmental concerns due to their use of lead. Various solutions are being pursued, as highlighted in the patent art.

## Solar efficiency roadmap

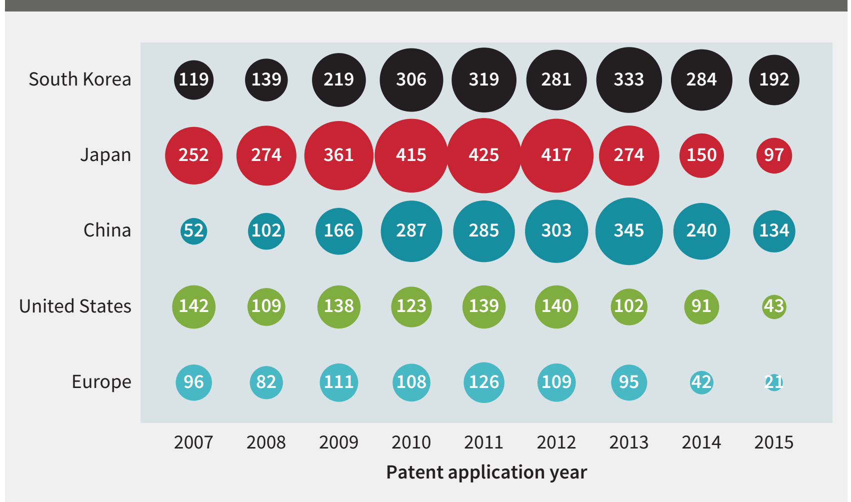
In the marketplace, current Gen 1 crystalline silicon solar cells have an average efficiency of 17% at a cost of $0.43/W, while Gen 2 cadmium telluride or copper indium gallium selenide solar cells have an efficiency of approximately 16.6% and 12.2%, respectively, at about $0.5/W. Silicon solar cells have benefited from 20 years of R&D, which has yielded significant improvements in efficiency and stability. However, the efficiency gains on the base technology have levelled off. Gen 3 and Gen 4 PV are newer technologies with the potential to transform the solar energy market within the next 10 years. This potential is illustrated by the trends in solar PV device efficiencies as published by the National Renewable Energy Laboratory. Figure 2 notes that Gen 3 PV have achieved an efficiency of around 12%, while Gen

**FIGURE 2.** Solar efficiency for emerging PV technologies



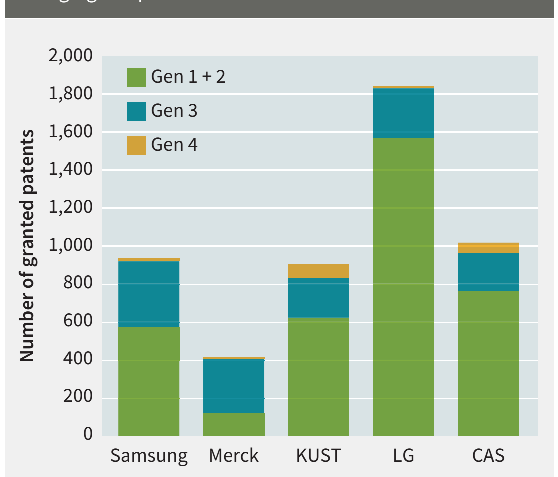

Source: The National Renewable Energy Laboratory

**FIGURE 3.** Number of granted patents in the top five jurisdictions




The area of the bubble represents the number of granted patents. Due to the delay between filing for a patent and it being granted, the filing data is shown up to December 2015.

**FIGURE 4.** Portfolio distribution of top five players in the emerging PV space



4 has shown an efficiency of 23% – a significant leap over all other solar technology. These trends have created great excitement from both a cost and efficiency perspective.

## Global patent filing trends for emerging solar technology

Our analysis of global patent activity relating to Gen 1, Gen 2, Gen 3 and Gen 4 PV has found that 88.7% of the total issued patents in this space were filed by players in China, Japan, the United States, South Korea and Europe (see Figure 3). In the 10-year period between the first quarter of 2007 and October 2018, 12,906 patents were granted from these jurisdictions. This translates into 8,947 unique granted patent families. At a high level, 2011 saw a significant increase in granted patents in South Korea, Japan and China. In contrast, filing activity by US and EU players remains significantly lower than that in Asia.

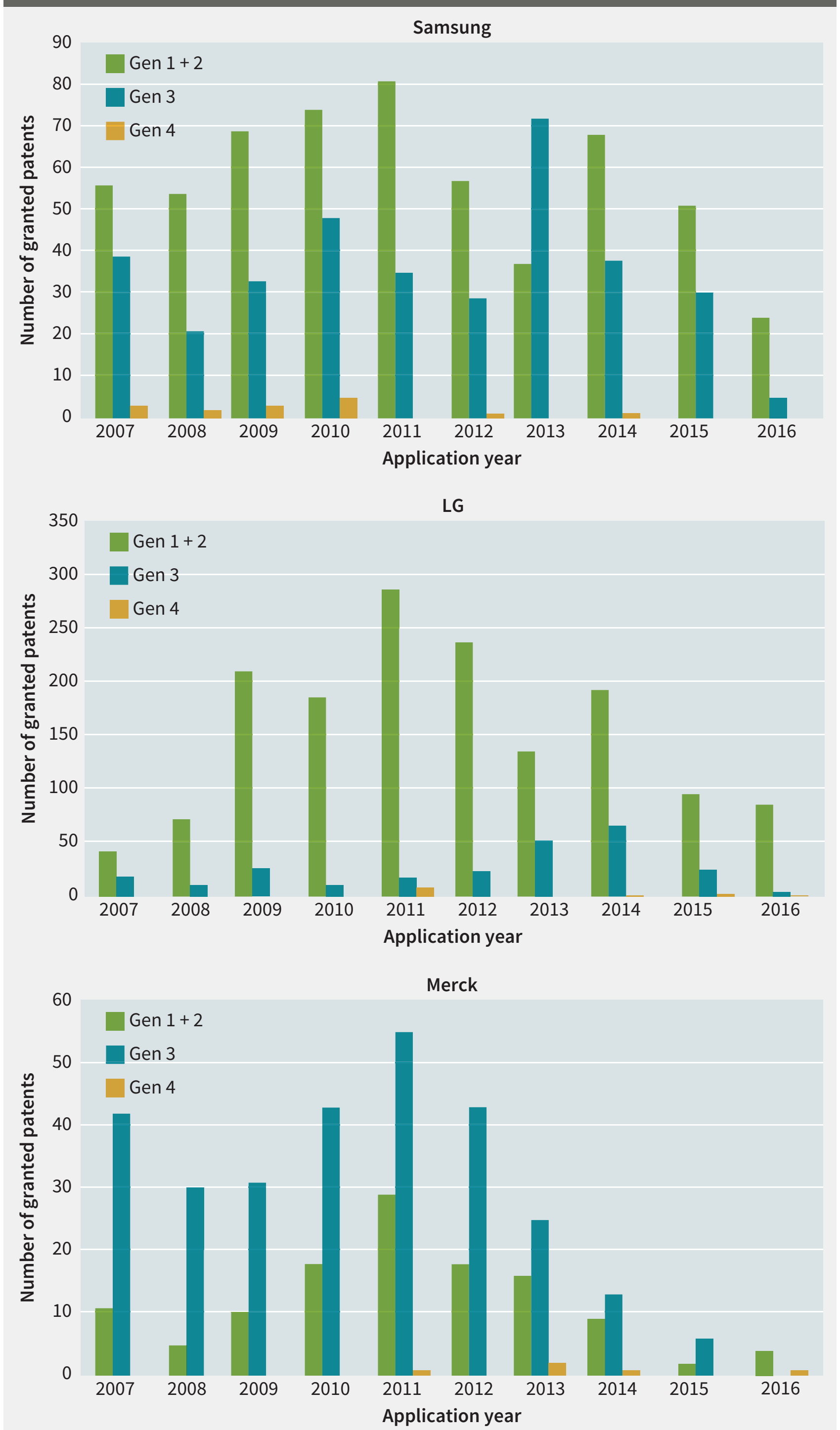
IP filings in these five jurisdictions correspond with the two major drivers behind success in PV technology, namely:

- strong expertise in semiconductor technology, in which many tools and processes are shared between organic light emitting diodes (OLEDs) and OPV technology; and
- significant domestic and global market demand.

A typical example is China, which created large internal demand for advanced solar technology through a national focus on strategic technologies and the need to scale up solar power in order to address climate change and environmental concerns. South Korea's domestic market for solar is projected to increase five times by 2030, continuing the country's investment in solar technology and strong IP development.

PV device efficiency can serve as a bellwether for industry shifts in R&D and patent activity. In general, technologies that experienced little improvement in efficiency were considered less promising, which has been reflected in falling interest and fewer patents. In contrast, the improvement in efficiency with Gen 3 utilising OPV technology between 2006 and 2012 created significant excitement and new interest, leading to IP growth. Similarly, device efficiencies for PVSC-based technologies continue to trend upward, which is a strong indicator of the potential for PVSC as a leading next-generation PV technology.

**FIGURE 5.** PV portfolios of Samsung, LG and Merck




## Leading players in the emerging PV space

Analysis reveals that the five organisations with the largest patent portfolios relating to emerging PV technologies are:

- Samsung (364 patents);
- Merck (292 patents);
- the Korean University of Science and Technology (KUST) (287 patents);
- LG (273 patents); and
- the Chinese Academy of Science (CAS) (258 patents).

Figure 4 illustrates that the portfolios of these organisations contain a spread of Gen 1 and 2, Gen 3 and Gen 4 patents.

The top five players fall into two main categories: large companies and research institutes.

### Large companies

The PV portfolios of large companies such as Samsung and LG over the past 10 years reveal a strategic focus on the continued development of traditional PV to achieve efficiency gains, supplemented with a gradual shift towards emerging technologies, especially Gen 3 (see Figure 5). Samsung's focus on Gen 3 technology (OPV) is multifaceted, with an emphasis on polymer compositions and manufacturing methods. Our data set also identified patents that focus on component layers, such as electrodes.

These component technologies can easily be applied to the manufacturing of OLEDs, of which Samsung is one of the world's largest producers. A similar strategy is taken by LG, which has a portfolio that focuses more on traditional PV and new OPV material and component layers. Similar to Samsung, LG's portfolio reflects a strategy to invest in core technologies with multiple product applications.

Compared to Samsung and LG, which have deep expertise in semiconductor and display technologies, Merck is focused on chemicals and process materials. From this perspective, Merck's patent portfolio focuses on OPV, which is heavily material dependent. Merck has the largest patent portfolio covering OPV technology and its filings peaked in 2011 (see Figure 5). Our analysis found that Merck's portfolio aligns with its core competence. This focus would also explain the absence of patents covering Gen 4 technology, as perovskites are a well-established material with numerous patents covering current production methods. As the market for Gen 3 and Gen 4 expands, Merck is well positioned to provide development support and materials to major product manufacturers.

**Research institutes**

KUST and CAS are leading players in advanced solar technology. Both research institutes have a long-term approach to R&D, which contrasts the short-term perspective of commercial companies. Their diverse R&D and patent portfolios cover both traditional PV and emerging PV technologies. In 2012 both institutes demonstrated a shift in PV research priorities, which was reflected in a decrease in traditional PV filings and attaining a leadership position with regard to Gen 4 technology (see Figure 6). This shift may be an early indicator of growing public interest in advanced solar technology with the large gains in cell efficiencies and its promising role as a clean energy source. Academic publications echo these findings, as a large number of PV publications describing advanced PV solar technology now originate from researchers in China, Japan and South Korea, according to *Energy Letters*. A diverse patent portfolio covering various aspects of advanced solar technology and manufacturing methods is perceived as the winning strategy to commercialising the next generation of solar technology.

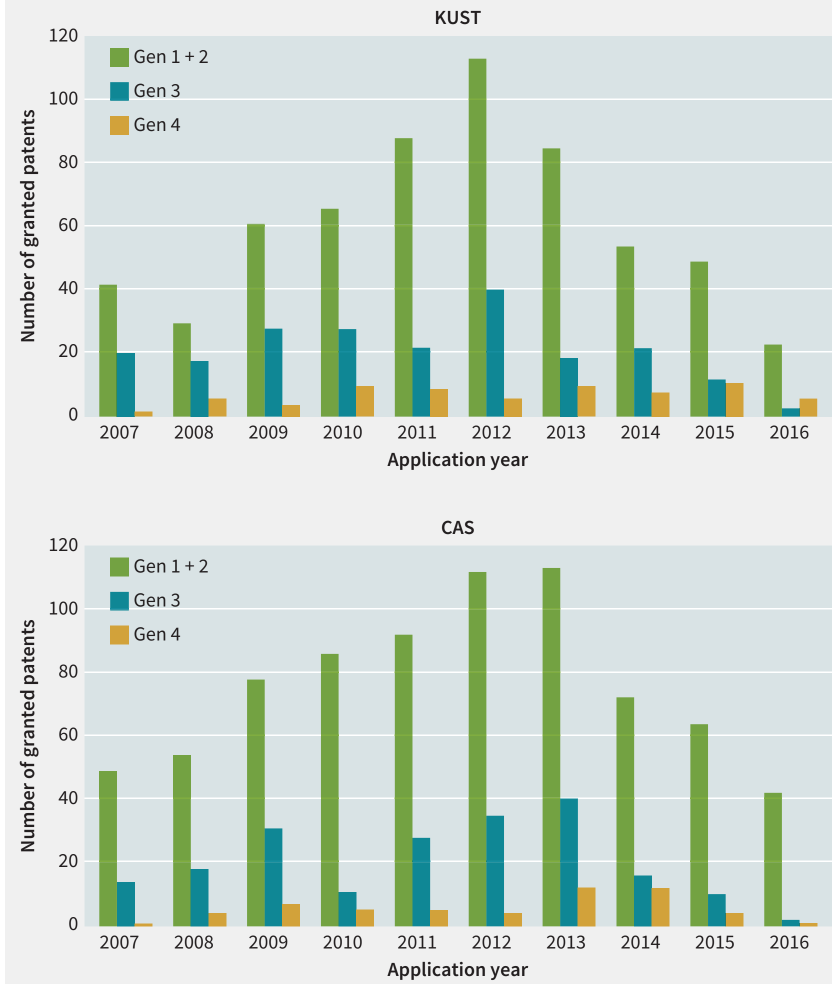
It is interesting to note the absence of US firms and research institutions from the top five players in the emerging PV space. Recent articles have reported that solar R&D spending by the US government dwarfs that of all other countries, with spending by the Chinese government at about 10% of US funding. The low level of US patent activity in emerging PV reflects the fact that federal R&D funds are heavily invested in traditional PV technology (an estimated 90%). This low US investment in advanced solar technology may be due to the distinct technical expertise required for R&D on Gen 3 and Gen 4, such as the development and processing of novel organic carbon-based materials and substrates for OPV. The technology departs largely from silicon-based manufacturing by using polymeric materials and associated production technologies.

## PVSC: an exciting new frontier

Our analysis of the emerging PV technology indicates a shift toward perovskites. The promise of high-efficiency PVSC is reflected in the R&D and patent focus of leading solar technology companies and research institutes (see Figure 2). It is also reflected in the literature, which highlights the excitement and potential of this promising Gen 4 technology. This consensus is echoed in reports issued by the Fraunhofer Institute, Advanced Science News and Lux Research, among others.

Moreover, this interest signals the likelihood of strong commercial growth for perovskites over the next five to 10 years, as various companies (eg, OxfordPV and Solar-Tectic) have announced plans to enter the market. Our analysis of the intellectual property in this space provides insight into the technical trends and opportunities, as well as the patents covering critical technology.

**FIGURE 6.** PV portfolios of KUST and CAS




*"A diverse patent portfolio covering various aspects of advanced solar technology and manufacturing methods is perceived as the winning strategy to commercialising the next generation of solar technology"*

**TABLE 1.** Four major PVSC technological developments

| Material improvements | Device improvements | Improved stability | Low-cost production |
|---|---|---|---|
| • Photo capture (active) materials<br>• Charge transport materials<br>• Electrodes or connective materials | • Active layer morphology<br>• New device architecture (ie, tandem, inverted solar cell)<br>• Device optimisation | • Moisture-resistant materials<br>• Moisture barrier<br>• Encapsulation materials and techniques | • Large-scale printable technology<br>• Low-temperature processing<br>• Materials use reduction (ie, solvents) |




Further, patent analysis creates a roadmap for navigating the following obstacles to widespread PVSC commercialisation (see Table 1):

- Material improvements – as perovskites find new applications in PV, material optimisation is required for PV application.
- Device improvements – like traditional PV, device architecture for PVSC is being developed and improved to maximise the material. State-of-the-art device architecture, such as tandem solar cells, is of high interest to the top players.
- Improved stability – one hurdle facing the adoption of PVSC is long-term stability, which can be improved by solutions such as encapsulation.
- Low-cost production – cost reduction through production optimisation is an area of high priority in the patent art.

The portfolio of top players can be further analysed from the perspective of these four major factors (see Figure 7).

**Research institutes**

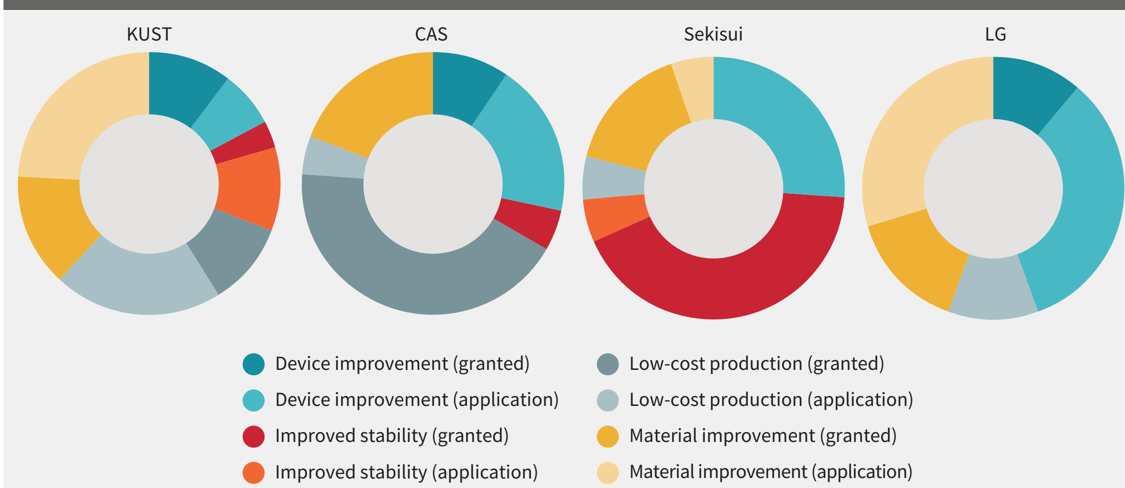
Patent analysis has found that KUST and CAS are the top players in PVSC. KUST is active in materials improvement (eg, through the use of lead-free and nanomaterials in PVSC) and is exploring various ways to lower production costs (eg, through low-temperature film formation, which can be scaled for mass production). CAS is more focused on low-cost production (eg, through the use of ink jet printing for perovskite deposition) and is active in device improvement (eg, through silicon/perovskite tandem PV, which we highlight as a breakthrough technology below). The focus of both institutes on low-cost production technology signals their interest in the commercialisation of PVSC in the coming years. Several important patents illustrate these efforts, including:

- KUST's South Korean Patent KR 1,723,824 B1 detailing an ionic polymer as a moisture barrier, yielding key stability for PVSC; and
- Chinese Patent CN 105,024,012 B, filed by CAS, detailing a production method utilising energy efficient methods (eg, low temperature) for the perovskite active layer.

**Large companies**

Sekisui is a Japanese PV producer with a PVSC portfolio focused on improved stability; for example, through the use of siloxane as a sealing layer or resin encapsulation. The company's patent applications are active in device development and its overall portfolio activity suggests that the company is currently developing products

**FIGURE 7.** Detailed perovskite solar cell portfolio analysis of top players



for commercial applications. In contrast, LG is much slower to shift to Gen 4 technology, as indicated above. However, its recent increased application activity demonstrates a significant interest in OPV/PVSC hybrid technology, as well as tandem device development using PVSC. LG's lack of interest in improved stability may suggest that the company is in the early stages of developing PVSC. Significant representative patents from these large companies include:

- Sekisui's Japanese Patent JP 6,154,058 B2 improving solar efficiency through a high degree of crystallinity in the perovskite layer; and
- LG's South Korean Patent KR 1,736,556 B1 laying the groundwork for new hybrid solar cells that could capture the benefit of both Gen 3 and Gen 4 technologies by using an OPV material to improve the material efficiency of PVSC component layers.

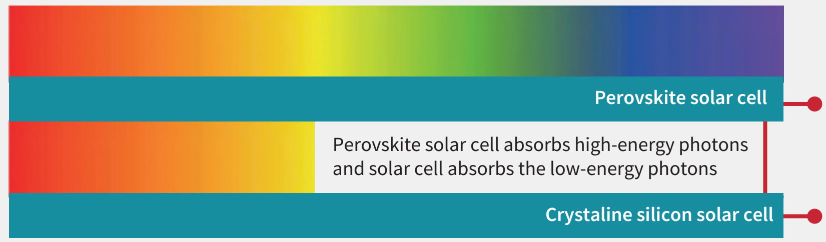
**United States and European Union**

Recent breakthroughs in Gen 4 technology have resulted in increased activity in the United States and European Union. There are several active US and EU companies (eg, Solar-Tectic and IBM) with small portfolios and a narrow focus on tandem solar cells. Oxford University is a top player in the European Union, with a portfolio that incorporates perovskites into Gen 3 DSSC technology. OxfordPV – a start-up from Dr Snaith's group at Oxford University – recently reported a perovskite-silicon tandem solar cell with an impressive 27.3% efficiency. Indeed, OxfordPV plans to have a commercially viable product by 2019. In the United States, a team composed of two research groups at Stanford University is focused on Gen 4 technology and is supported by funding from the DOE's SunShot Initiative.

## Breakthrough technology: PVSC tandem solar cell

Our analysis of various portfolios has found that one breakthrough technology with huge potential is the tandem device architecture (see Figure 8). The sun's solar output encompasses a wide spectrum of wavelengths and no one material can efficiently capture the entire energy spectrum. Therefore, it is much more productive to separate and optimise energy collection with complementary material cells. A typical tandem solar cell may combine a traditional silicon device with a Gen 4 PVSC layer to theoretically achieve a device efficiency of 30% or higher. In such a device, the solar energy would first be exposed to the PVSC device, while the remaining energy would then penetrate the silicon solar cell. PVSC (Gen 4) is optimised to capture the blue wavelengths of the solar spectrum, while silicon is optimised for the red wavelengths. The combined effect is more energy absorption over a broader portion of the solar spectrum. The patent analysis identified several innovative tandem solar cells, which are highlighted in Table 2.

**FIGURE 8.** Representative tandem solar cell for high-efficiency PV applications



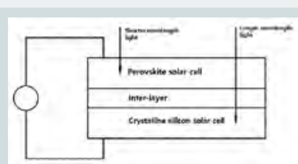

*"Gen 3 and Gen 4 PV will likely play a key role in addressing climate change, with products due to roll out over the next three to five years, with broad commercialisation to follow"*

## Insight from intellectual property

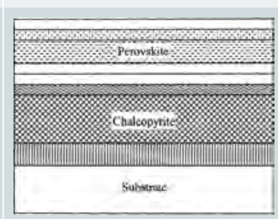
Analysis of the patent landscape covering next-generation solar PV technologies provides detailed insight into the trajectory of global innovations and the IP portfolios of key players at work in this area. Gen 3 and Gen 4 PV will likely play a key role in addressing climate change, with products due to roll out over the next three to five years, with broad commercialisation to follow. IP analysis provides valuable insight into the

**TABLE 2.** Examples of tandem solar cells from various players

<table>
<tr><th>PVSC player</th><th>Oxford University</th><th>LG</th><th>Solar-Tectic</th><th>IBM</th></tr>
<tr><td>Patent number</td><td>US 10,069,025 B2</td><td>US 20180158976 A1</td><td>US 20170271622 A1</td><td>US 9,627,576 B2</td></tr>
<tr><td>Patent title</td><td>Optoelectronic device</td><td>Tandem solar cell and method of manufacturing the same</td><td>High efficiency thin film tandem solar cells and other semiconductor devices</td><td>Monolithic tandem chalcopyrite-perovskite photovaltaic device</td></tr>
<tr><td>Representative example</td><td>

Utilises either a Generation 1 or 2 solar cell in tandem with a perovskite solar cell</td><td>

Crystalline-silicon: perovskite tandem solar cell</td><td>

Perovskite: perovskite tandem solar cell</td><td>

Chalcopyrite: perovskite tandem solar cell</td></tr>
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## Action plan

For investors, senior managers and IP strategists, this patent-driven approach provides critical insight into the future trajectory of advanced PV technologies, the most promising technologies and patent portfolios of diverse players. It also provides crucial information for assessing the likely winner and losers. Some useful applications include:

- assessing patent portfolio position and strength germane to Gen 3 or Gen 4 PV;
- identifying product strategies that exploit key technology and IP trends;
- identifying opportunities (white space) to guide crafting strong patents;
- understanding options to accelerate R&D and product development;
- assessing IP licensing options surrounding next-generation solar technology; and
- identifying joint venture partners with complementary expertise and intellectual property.

most promising technologies, holders of critical patents and future product directions. However, such detail can be obscured by a high-level view that focuses solely on the number of patents held by assignees, rather than their specific coverage. These insights can guide company strategists, investors and R&D managers seeking to assess the opportunities.

Analysis of the emerging solar PV patent landscape provides detailed insight into global trends, as well as the major players at work in this area. When considering IP development in the PV sector, Asian jurisdictions must be carefully considered, as they provide leading producers, consumers and developers. The use of patent and literature data with our technological analysis reveals the different strategic approaches that are being taken by individual players, including large companies and research institutes.

When considering IP portfolio development and strategy in the PV area, Asian jurisdictions (primarily, China, South Korea and Japan) must again be carefully considered, as they have strong IP portfolios and are leading manufacturers. Integrating IP data with technical analysis provides a snapshot of the strategic direction and focus of individual players (eg, large companies, research institutes and start-ups). The patent analysis also illuminates a path forward for companies seeking to accelerate their R&D activity and IP filings, as well as to capture the immense opportunity created by Gen 3 and Gen 4. Lastly, governments can be a major driver in accelerating the development of advanced PV technologies through increased financial support for research institutes, universities and start-ups. If solar energy is to provide 25% of the world's energy capacity in 25 years, a global commitment is needed to harness the immense talent necessary to achieve explicit goals in PV energy efficiency, cost and manufacturing. iam

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