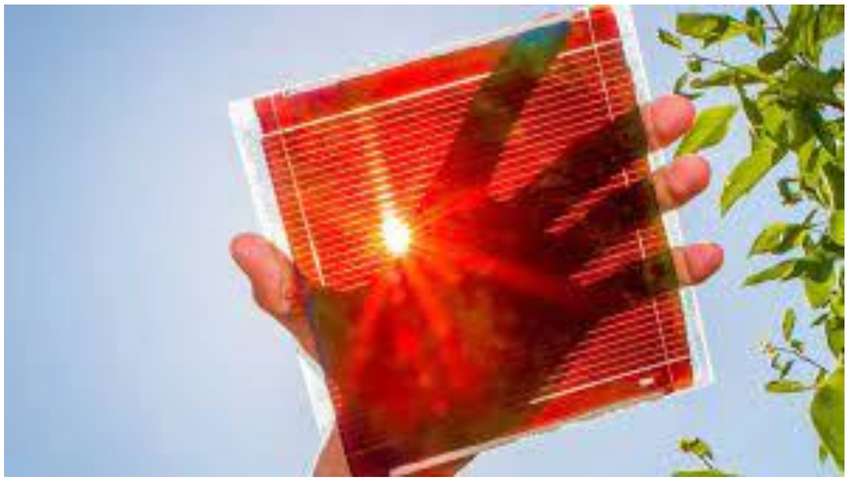
The (Potential) Role of Perovskites in the Future of Solar Energy



Source: SolarReviews

A recent (November 2023) article posted by EnergyS on LinkedIn was titled ***Are Perovskite Solar Cells The Future of Solar Technology?*** The article reported that Perovskite solar cells have emerged as a major development in solar energy. It discussed Perovskite's ability to absorb light more efficiently than traditional silicon cells (which represent about 95% of all solar cells), leading to significantly higher efficiency. It mentioned recent research from a Chinese solar technology firm that had reported achieving a record 33.9% efficiency for a silicon-perovskite tandem solar cell. (Solar cell efficiency, which is known as the Power Conversion Efficiency, or PCE, is the amount of solar energy that can be converted to electricity by a solar cell). The article also mentioned other research in China which could enable mass production of panels that would be as much as 50% cheaper than traditional silicon cells.

By comparison, industrially produced solar modules currently achieve efficiencies ranging from 18%–22% under standard conditions (with up to 25% being achieved with some single-crystal cells).

The article also discussed work being done at an Australian university that leverages AI and has created reproducible perovskite solar cells with a power-conversion efficiency of 16.9%. The use of AI not only accelerates the development of these cells but also enhances their reproducibility, a critical factor in transitioning from laboratory to commercial-scale production. This method allows developers to more easily create and test new solar cells, with the ability to learn from and improve upon earlier versions.

The article concluded with the following statement: "the combination of enhanced efficiency, reduced costs, and innovative production methods positions Perovskite technology as a key player in the future of solar energy."

There was also another recent LinkedIn article on Perovskites – this one posted by Precision Reports and entitled ***Perovskite Solar Cells Market is set to see Revolutionary Growth in Decade*.** This article stated that the global market for Perovskite Solar Cells was valued at $414 million in 2021 and is expected to reach $825 million by 2027 and continue to grow from there[1].

So, what exactly is a Perovskite solar cell, why does it appear to have such potential, and what is the current state of the market?

What is a Perovskite Solar Cell?

If Perovskite sounds like a Russian word, that is because it was named for a Russian.

Perovskite is a naturally occurring calcium titanium mineral with a chemical formula of $CaTiO_3$. This mineral was first discovered by German mineralogist Gustav Rose in 1839 in the Russian Ural Mountains and was named in honor of the Russian mineralogist Lev Perovski. The name Perovskite is also applied to a class of compounds which have the same type of crystal structure - known as the perovskite structure.

A perovskite solar cell (PSC) is a type of cell that includes a perovskite-structured compound, most commonly a hybrid organic–inorganic lead or tin halide-based material, as the light-harvesting active layer. Perovskite materials, such as methylammonium lead halides and all-inorganic cesium lead halides, are simple to manufacture. As noted above, Perovskites have shown potential for both high performance and low production costs for solar cells.

In 2009, Japanese engineer Tsutomu Miyasaka reported that he and his colleagues had used organic–inorganic lead halide perovskite compounds as light absorbers in solar cells. These materials had been investigated for many years and had been used in applications such as light-emitting diodes, but this was the first attempt to use perovskites in solar cells. But Miyasaki's device delivered only a 3.8% power conversion efficiency and was stable for only a few minutes, so the general reaction was to question whether perovskites had a real potential role in photovoltaics.

That being said, research into perovskite solar cells continued across multiple countries, and significant progress has occurred over these past 15 years. In 2012, research teams in Switzerland and South Korea demonstrated solid-state perovskite photovoltaic devices that largely overcame the poor stability of the material. Later in 2012, a research team in the UK demonstrated that the materials are not only able to sensitize a semiconductor, but also transport electronic charges to the solar cell electrodes, enabling higher device efficiencies. Organic–inorganic lead halide perovskites thus became the front runners among emerging photovoltaic materials and the field has advanced dramatically since.

[1] I am a bit confused by the 2021 number, since, as will be discussed below, we are barely beginning to see perovskite solar cells become commercially available.

Perovskite solar cells have shown remarkable progress in recent years with rapid increases in efficiency, to over 30% today, as noted above. Another successful test was reported in May 2023, by UK-based Oxford Photovoltaics, which reported that it had achieved an efficiency of 28.6% for a commercial-size perovskite *tandem cell* where the perovskite material was combined with a conventional silicon solar cell (more on tandem cells shortly). They reported this as the record efficiency that had been achieved at that time, and the efficiency level was independently certified by Fraunhofer ISE (who is also developing perovskite solar cells).

Lab Manufactured Perovskite Solar Panel: Source – PV Magazine

Perovskites' ability to make electricity can be "tuned" by controlling the kinds of molecules that are produced in the manufacturing process. This tuning can result in materials with a better "bandgap" - the minimum amount of energy needed to push an electron to a higher energy level so it can carry an electrical charge. Perovskites can be tuned to various bandgaps within a wide range, while other materials only have one. By controlling the chemical makeup of a perovskite crystal, materials scientists can manufacture perovskite materials to have a bandgap very close to ideal for converting light to electricity, but they can also create multi-layered perovskite solar cells in which each layer has a different bandgap. Having multiple layers means high-energy photons excite electrons in layers with a wider bandgap, and low-energy photons excite electrons in layers.

In addition to the higher efficiency potential, perovskite solar cells can potentially be manufactured significantly more cheaply than traditional silicon cells. Silicon must first be heated to extremely high temperatures to produce a material with the right purity and crystal structure to make electricity; perovskites can be created by simply mixing chemicals in a solution and coating a surface with that solution. The process has some complications but, generally speaking, producing perovskite solar cells should be cheaper and easier than making silicon cells. Perovskite production requires significantly fewer materials than silicon cells and doesn't use any rare earth metals. Furthermore, the manufacturing process is much less energy intensive than the manufacturing of traditional solar cells.

While perovskite solar cells have become highly efficient in a very short time, a number of challenges remain before they can become a truly competitive commercial technology, as discussed in the next section.

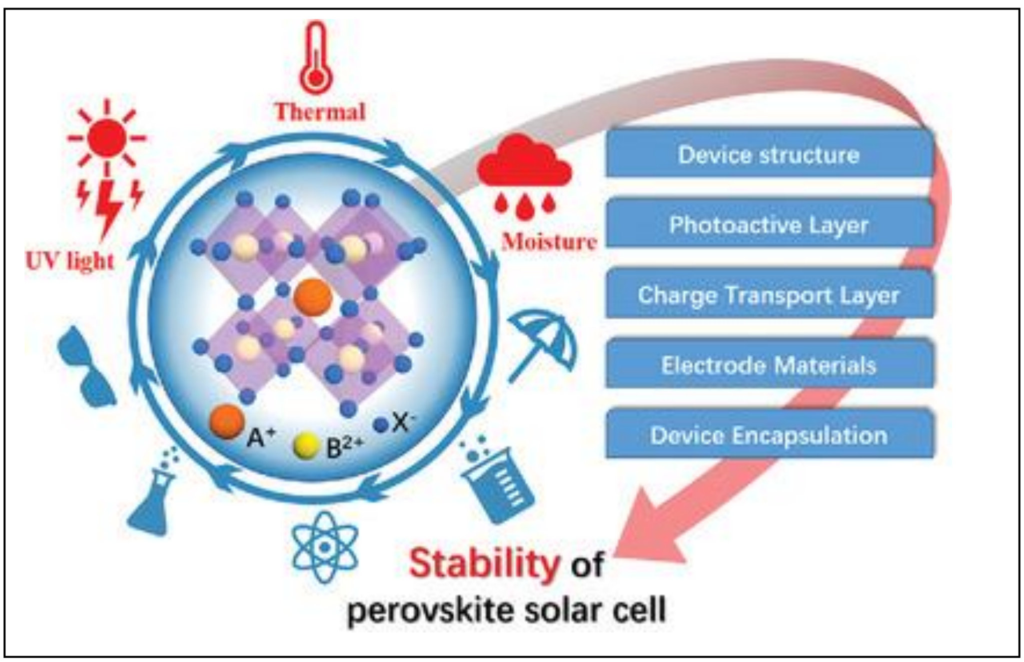
Barriers to the Widespread Adoption of Perovskite Solar Cells

Issues that will need to be addressed before we will see perovskite be widely used are discussed include the following.

1. Stability and Durability

Perovskite solar cell stability is limited compared to current PV technologies. Perovskites can decompose when they react with moisture and oxygen or when they spend extended time exposed to light, heat, or applied voltage.

To increase stability, researchers are studying degradation in both the perovskite material itself and the surrounding device layers. Improved cell durability is critical for the development of commercial perovskite solar products. Early perovskite devices degraded rapidly, becoming non-functional within minutes or hours. More recently, multiple research groups have demonstrated lifetimes of several months of operation. However, that is still dramatically below that of other PV technologies.



Source: Wiley Online Library

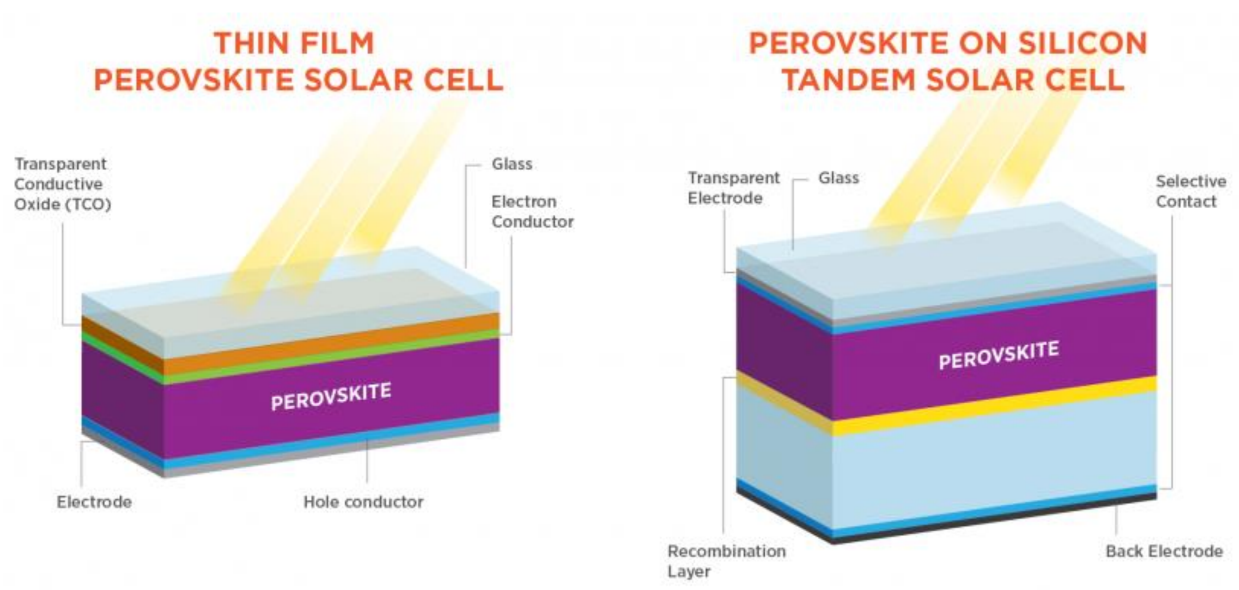
Perovskite PV researchers are exploring multiple approaches to reducing degradation and improving stability. These include improved treatments aimed at decreasing the reactivity of the perovskite surface, alternative materials (and formulations) for perovskite materials and advanced encapsulation materials, alternative surrounding device layers, and various approaches to mitigating degradation sources during fabrication and operations.

The U.S. Department of Energy Solar Energy Technologies Office (SETO) supports research and development projects aimed at increasing the efficiency and lifetime of perovskite solar cells, speeding the commercialization of perovskite solar technologies and decreasing manufacturing costs. For commercial, grid-level electricity production, SETO is targeting an operational lifetime of at least 20 years, and preferably more than 30 years.

2. Power Conversion Efficiency at Scale

While, as noted earlier, thin-film perovskite PV cells have recently exceeded almost all thin-film solar cell technologies in power conversion efficiency, this has been largely with small in-lab devices, and no one has yet shown that these high-efficiency devices can be fabricated at large scale.

Perovskites can be tuned to respond to different colors in the solar spectrum by changing the material composition, and a variety of formulations have demonstrated high performance. Perovskites can be combined with another, differently tuned absorber material to deliver more power from the same device – potentially with efficiencies in excess of 30%. This is known as ***tandem*** device architecture – which is what Oxford PV was testing. Perovskite materials can be tuned to take advantage of the parts of the solar spectrum that silicon PV materials can't use very efficiently, meaning they make excellent hybrid-tandem partners. It is also possible to combine two perovskite solar cells of different composition to produce a perovskite-perovskite tandem. Perovskite-perovskite tandems could be particularly competitive in the mobile, disaster response, and defense operations sectors, as they can be made into flexible, lightweight devices with high power-to-weight ratios.



Thin-film vs Tandem Solar Cell Structure. Image Source: US Department of Energy

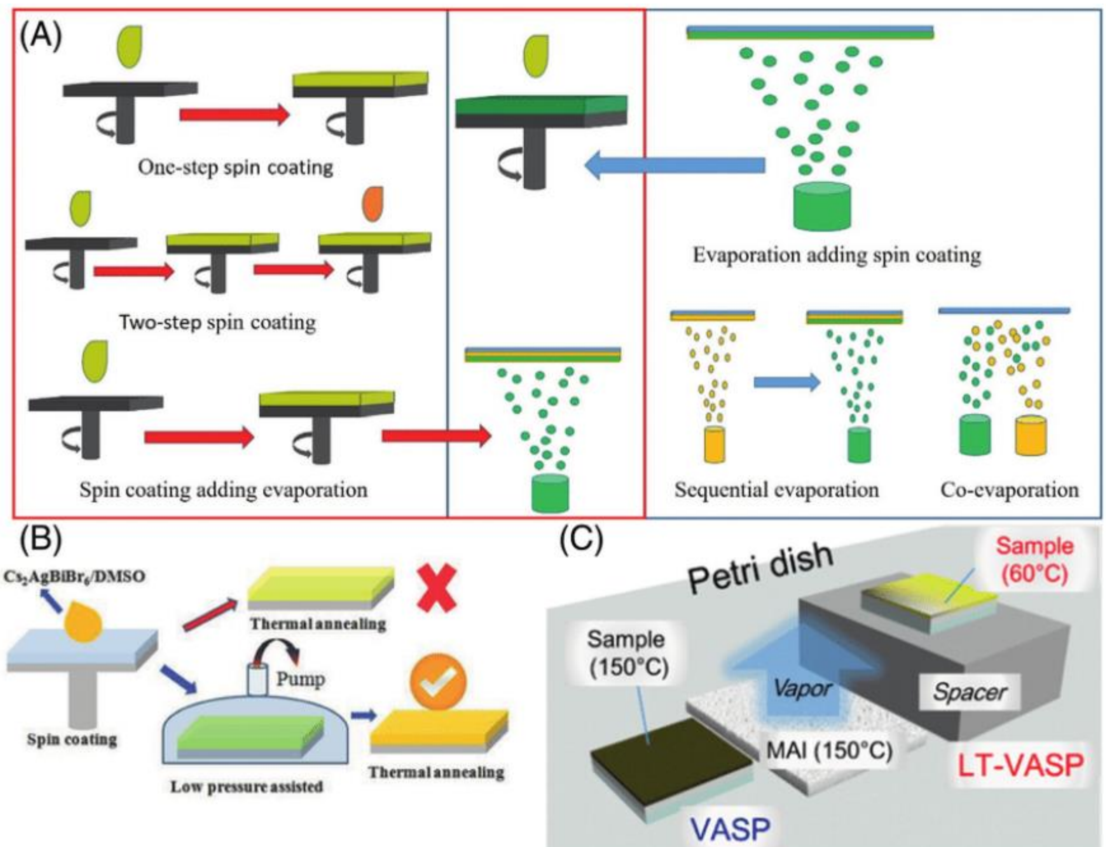
3. Manufacturability

Producing uniform, high-performance perovskite material in a large-scale manufacturing environment is still difficult, and there is a substantial difference in small-area cell efficiency and large-area module efficiency. The future of perovskite manufacturing will depend on solving this challenge, and significant efforts are being made to develop scalable approaches to perovskite fabrication.

For example, there are two major production approaches being applied for thin-film technologies:

- *Sheet-to-Sheet:* Device layers are deposited on a rigid base, which typically acts as the front surface of the completed solar module. This approach is commonly used with cadmium telluride (CdTe) - which is the second most common material used for solar cells.
- *Roll-to-Roll:* Device layers are deposited on a flexible base, which can then be used as either an interior or exterior portion of the completed module. Researchers have tried this approach for other PV technologies, but roll-to-roll processing did not gain traction because of performance limitations.

Both of these processes are well established in other industries. If perovskites can be made reliably using these approaches, they have the potential for faster capacity expansion than silicon PV.



Fabrication Processes of the Lead-Free Perovskite Solar Cells (PSCs). (A) Summary of the spin-coating and evaporation process. (B) Low-pressureassisted fabrication process [32]. (C) Schematic of the vapor-assisted solution process (VASP) and low-temperature VASP (LT-VASP) fabrication processes [36].

Source: ResearchGate

Another manufacturing issue is that perovskites with the highest efficiencies contain lead, which is a neurotoxin. (Attempts to replace lead with tin have resulted in much lower efficiency so, while there has been progress on this issue, more work is needed). The industry is working on multiple approaches for reducing the toxicity of perovskites.

4. Performance Validation

Performance validation is essential to the commercialization of perovskite technologies. Variability in testing protocols and lack of sufficient field data have limited the ability to compare performance across perovskite devices and to develop the confidence in long-term operational behavior required to drive investment in production scale-up and deployment.

Current testing protocols for solar PV devices were developed for mainstream PV technologies. These involve indoor testing using protocols that can also accurately predict outdoor performance in silicon and cadmium telluride solar cells, which degrade very differently than perovskite technologies. Objective validation that uses protocols that can reliably screen for real-world failure modes is critical to ramping up confidence in perovskite technologies. The rapidly changing material and device compositions of perovskite solar cells make this standardized validation particularly challenging.

To try to address this, SETO has funded the Perovskite Photovoltaic Accelerator for Commercializing Technologies (PACT) Validation and Bankability Center. PACT will conduct field and lab testing, develop and validate accelerated test protocols and energy yield models, and conduct technical studies with a goal of improving understanding and confidence in the efficiency and durability of perovskite PV technologies. SETO has also developed performance targets to support perovskite PV commercialization efforts. These targets - for efficiency, stability and replicability of perovskite PV devices - are intended to align research directions and goals and ensure that future funding programs are relevant for accelerating technical and commercial development and de-risking of perovskite technologies.

Companies Working on Perovskite Solar Cells

Despite the fact that perovskite solar cells are just on the verge of becoming commercially available and there is still a lot of work to do before they become widely used, there are a large number of companies working on the technology – which contributes to the excitement about the future of perovskites. Companies in this space are located all over the world – with a lot in China and Japan but also quite a few in North America, Europe, and elsewhere. Here is a list of many – but certainly not all - of these companies.

	Dyenamo	Sweden	**Power Roll**	New Zealand	
	Energy Materials	US	**Rayleigh Solar Tech**	Canada	
	Fraunhofer ISE	Germany	**RenShine Solar**	China	
	FrontMaterials	China	**Saule Technologies**	Poland	
	GreatCell Solar	Australia	**Sharp**	Japan	
	Hangzhou Microquanta	China	**Solaires**	Canada	
	Jinko Solar	China	**Swift Solar**	US	
	Kyocera	Japan	**Tandem PV**	US	
	Merck KGaA	Germany	**Toshiba**	Japan	
	Oxford PV	UK			

Companies Working on Perovskite Solar

Bottom Line

The cost of Solar PV has dropped markedly over the past 10 years, and the performance has increased dramatically which has led to a dramatic growth of PV installations both on buildings and at the grid level.

Now a new take on Solar PV – Perovskite Solar PV – has the potential to further enhance performance and significantly reduce costs. As laid out in this article, there is still a lot of work to be done to make that happen, but a multitude of companies are working on it and funding has been made available in the US and elsewhere to accelerate the research. It is still unclear how long it will take for the use of Perovskite Solar to skyrocket – but all of the evidence points to it happening.