<u>**Utility scale solar PV**</u>

OVERVIEW

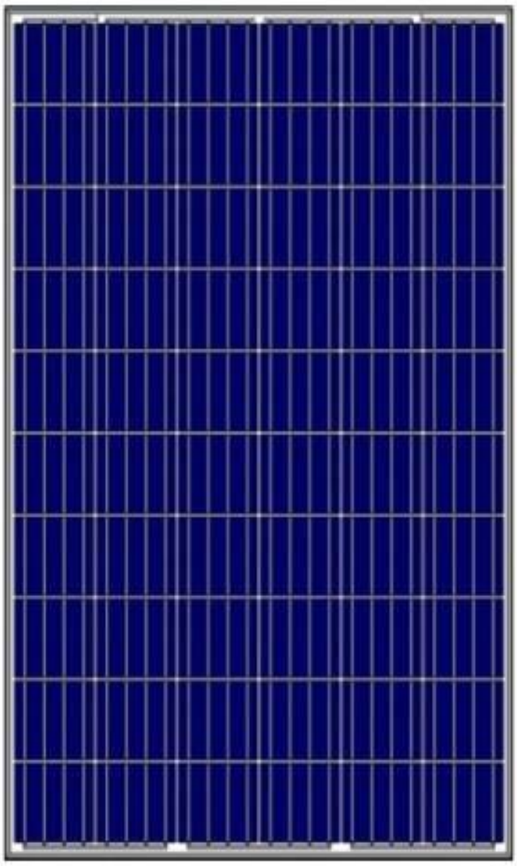
The share of electricity in the total energy mix will be more than double to 40% by 2050. Renewable energy, led by solar photovoltaic (PV), will supply that growth and replace much of today's fossil-fuel generated electricity. In the last decade the global installed capacity of solar generation increased more than tenfold studies state that 60 percent of global electricity generation to come from solar energy by 2050.

AFEA POWER will utilise the most commercially operable types of solar panels to convert the solar energy into electricity. These photovoltaic (PV) technologies include monocrystalline silicon panels, polycrystalline silicon panels, and thin-film panels. Depending on the solar potential, geographical location, and financial requirements of a specific solar PV project, a suitable PV system is implemented to meet the project's needs. The solution will focus on the use of solar PV systems bigger than 10 megawatts to generate electricity.

MONOCRYSTALLINE

Monocrystalline silicon solar cells are manufactured using something called the Czochralski method, in which a ‘seed’ crystal of silicon is placed into a molten vat of pure silicon at a high temperature. This process forms a single silicon crystal, called an ingot, that is sliced into thin silicon wafers which are then used in the solar modules. Typically, the efficiency of monocrystalline cells ranges from 15%-20% but the highest quality panels can reach up to 23% efficiency The monocrystalline silicon cells are believed to be very durable and last over 25 years. fficiency declines by about 10% when the ambient temperature rises by 25 °C, so replacement of operating modules might be needed sooner. The main disadvantages of the monocrystalline silicon panels are high initial cost and mechanical vulnerability brittle Monocrystalline silicon cells are highly efficient, but their manufacturing process is slow and labour intensive, making them more expensive than their polycrystalline or thin film counterparts.

<u>POLYCRYSTALLINE</u>



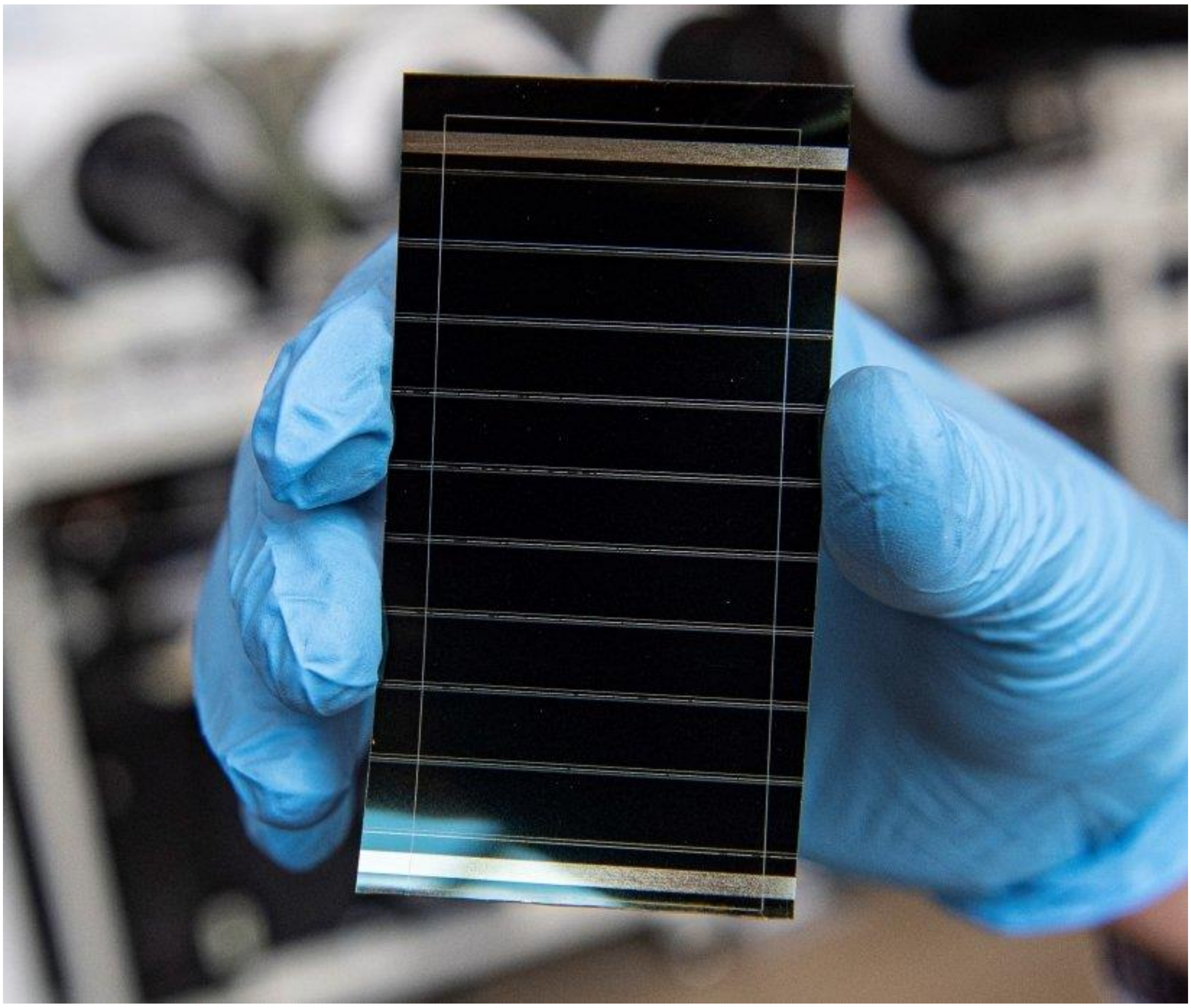
Polycrystalline panels, also known as multicrystalline panels, are made by assembling multiple grains and plates of silicon crystals into thin wafers. The silicon molecular structure consists of several smaller groups or grains of crystals, which introduce boundaries between them the manufacturing cost of this type of PV is less than that of monocrystalline silicon cells. Cell efficiency typically is 13% to 16%. Polycrystalline silicon is also widely used because it is less expensive than monocrystalline silicon. These cells can be recognized by their mosaic-like appearance. Polycrystalline cells are also very durable and may have a service life of more than 25 years. The cons of this type of PV technology are mechanical brittleness and not very high efficiency of conversion They are popular among homeowners looking to install solar panels on a budget.

THIN FILM SOLAR PANELS

Thin Film panels are photovoltaic types of cells which were originally developed for space applications with a better power-to-size and weight ratio compared to the previous crystalline silicon devices. As their name suggests, thin-film panels are often slimmer than other panels. This is because the cells within the panels are roughly 350 times thinner than the crystalline wafers used in monocrystalline and polycrystalline solar panels. The biggest differentiating aesthetic factor when it comes to thin-film solar panels is how thin and low-profile the technology is. It's important to keep in mind that while the thin-film cells themselves may be much thinner than traditional solar cells, an entire thin-film panel may be similar in thickness to a monocrystalline or polycrystalline solar panel if it includes a thick frame. There are adhesive thin-film solar panels that lie as-close-as-possible to the surface of a roof, but there are more durable thin-film panels that have frames up to 50 millimetres thick. Thin film solar panels have incredibly low efficiency ratings. As recently as a few years ago, thin film efficiencies were in the single digits. Researchers have recently achieved 23.4% efficiency with thin film cell prototypes but thin film panels that are commercially available generally have efficiency in the 10–13% range

1. Solar Energy Technologies Office
2. Perovskite Solar Cells

The U.S. Department of Energy Solar Energy Technologies Office (SETO) supports research and development projects that increase the efficiency and lifetime of hybrid organic-inorganic perovskite solar cells, speeding the commercialization of perovskite solar technologies and decreasing manufacturing costs.



Perovskite solar cell.
Dennis Schroeder / National Renewable Energy Laboratory

What are Perovskite Solar Cells?

Halide perovskites are a family of materials that have shown potential for high performance and low production costs in solar cells. The name "perovskite" comes from the nickname for their crystal structure, although other types of non-halide perovskites (such as oxides and nitrides) are utilized in other energy technologies, such as fuel cells and catalysts.

Perovskite solar cells have shown remarkable progress in recent years with rapid increases in efficiency, from reports of about 3% in 2009 to **over 25%** today. While perovskite solar cells have become highly efficient in a very short time, a number of challenges remain before they can become a competitive commercial technology.

Research Directions

SETO has identified four primary challenges that must be simultaneously addressed for perovskite technologies to be commercially successful. Each challenge represents a unique set of barriers and requires specific technical and commercial targets to be achieved. The office is supporting projects working to address these challenges through **several funding programs**, including the **SETO FY2021 Small Innovative Projects in Solar (SIPS)**, **SETO 2020 Photovoltaics**, and **SETO FY20 Perovskite** funding programs, as well as the **Perovskite Startup Prize**.

Learn more about SETO's perspective on perovskites in our **Energy Focus article** and our request for information on **performance targets**.

STABILITY AND DURABILITY

Perovskite solar cells have demonstrated competitive power conversion efficiencies (PCE) with potential for higher performance, but their stability is limited compared to leading photovoltaic (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.

Despite significant progress in understanding the stability and degradation of perovskite solar cells, they are not currently commercially viable because of their limited operational lifetimes. Commercial applications outside the power sector may tolerate a shorter operational life, but even these would require improvements in factors such as device stability during storage. For mainstream solar power generation, technologies that cannot operate for more than two decades are unlikely to succeed, regardless of other benefits.

Early perovskite devices degraded rapidly, becoming non-functional within minutes or hours. Now, multiple research groups have demonstrated lifetimes of several months of operation. For commercial, grid-level electricity production, SETO is targeting an operational lifetime of at least 20 years, and preferably more than 30 years.

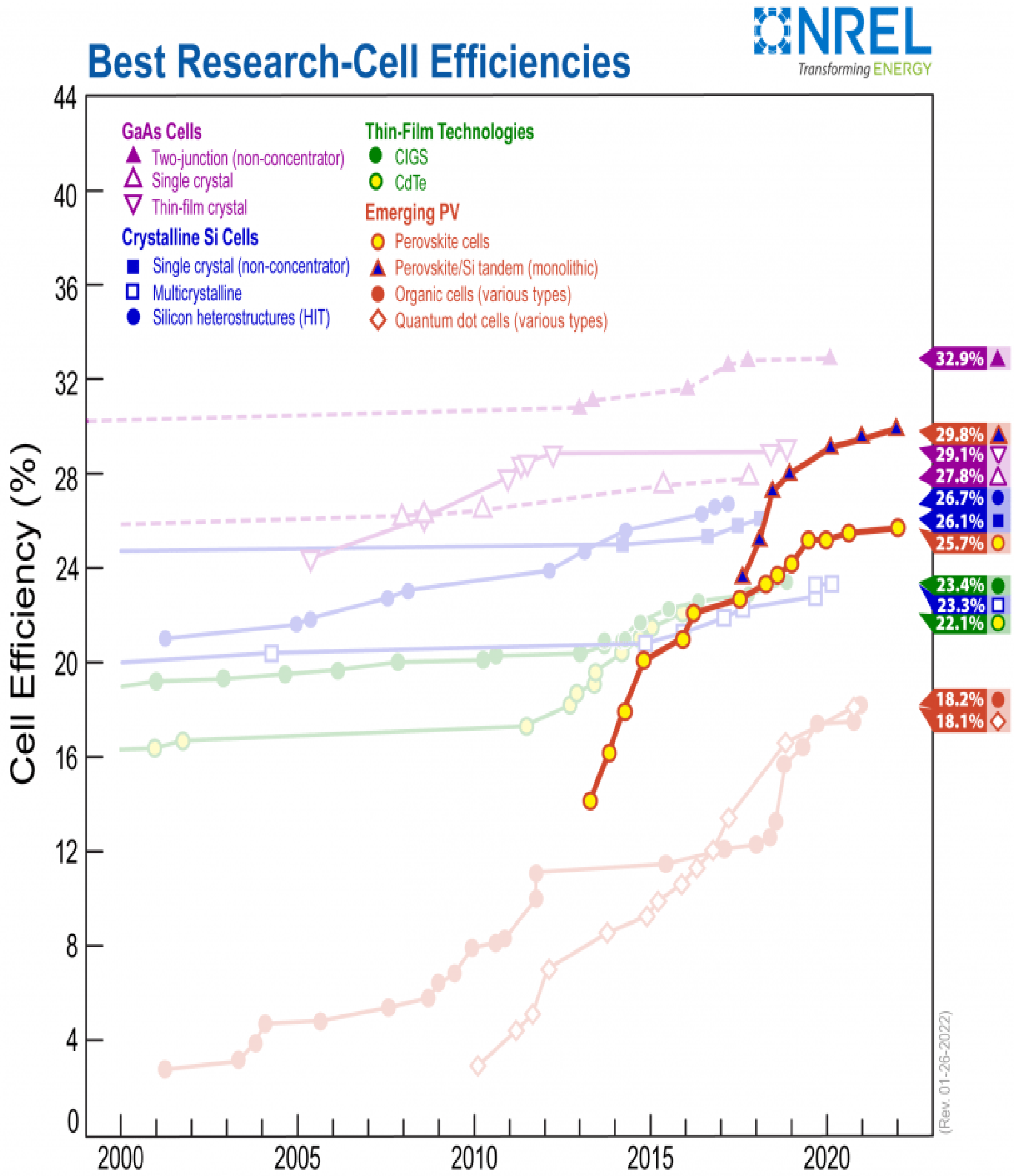
The perovskite PV research and development (R&D) community is heavily focused on operational lifetime and is considering multiple approaches to understand and improve stability and degradation. Efforts include improved treatments to decrease the reactivity of the perovskite surface, alternative materials and formulations for perovskite materials, alternative surrounding device layers and electrical contacts, advanced encapsulation materials, and approaches that mitigate degradation sources during fabrication and operation.

One issue with assessing degradation in perovskites is developing consistent testing and validation methods. Research groups report performance results based on highly varied test conditions, including different encapsulation approaches, atmospheric compositions, illumination, electrical bias, and other parameters.

While such varied test conditions can provide insights and valuable data, the lack of standardization makes it challenging to directly compare results and difficult to predict field performance from test results.

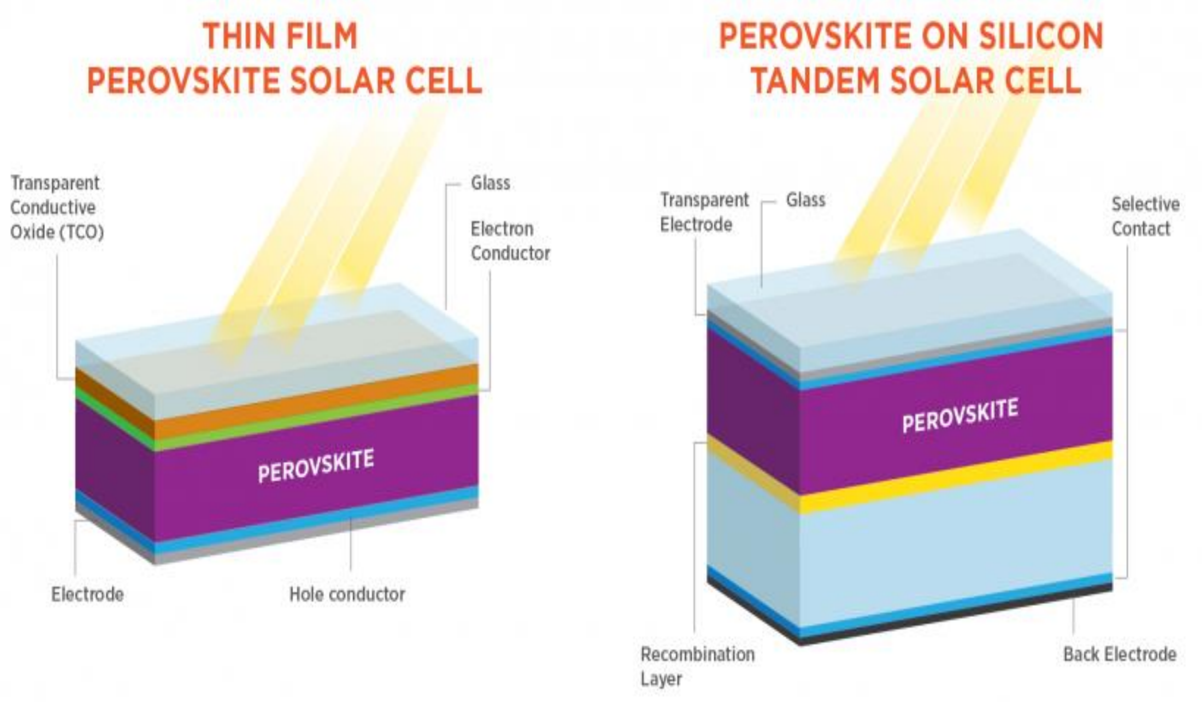
POWER CONVERSION EFFICIENCY AT SCALE

In small-area lab devices, perovskite PV cells have exceeded almost all thin-film technologies (except **III-V technologies**) in power conversion efficiency, showing rapid improvements over the past five years. However, high-efficiency devices have not necessarily been stable or possible to fabricate at large scale. For widespread deployment of perovskites, maintaining these high efficiencies while achieving stability in large-area modules will be necessary. Continued improvement in efficiency in medium-area modules could be valuable for mobile, disaster response, or operational energy markets where lightweight, high-power devices are critical.



Efficiency records for perovskite PV cells compared to other PV technologies, with current records of 25.7% for single junction perovskite devices and 29.8% for tandem perovskite-silicon devices (as of January 26, 2022).
National Renewable Energy Laboratory

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. This flexibility allows perovskites to be combined with another, differently tuned absorber material to deliver more power from the same device. This is known as a tandem device architecture. Using multiple PV materials enables tandem devices to have potential power conversion efficiencies over 33%, the theoretical limit of a single junction PV cell. 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.



MANUFACTURABILITY

Scaling up perovskite manufacturing is required to enable commercial production of perovskite solar cells. Making the processes scalable and reproducible could increase manufacturing and allow perovskite PV modules to meet or exceed SETO’s **levelized cost of electricity goals** for PV.

Perovskite solar cells are thin-film devices built with layers of materials, either printed or coated from liquid inks or vacuum-deposited. Producing uniform, high-performance perovskite material in a large-scale manufacturing environment is 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, which remains an active area of work within the PV research community.

Many of these methods used to produce lab-scale perovskite devices are not easy to scale up, but there are significant efforts to apply scalable approaches to perovskite fabrication. For thin-film technologies, these can be split into two major production types:

- *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 in the **cadmium telluride (CdTe) thin-film** industry.
- *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 commercial traction because of the performance limitations of these technologies. However, it is widely used to produce photographic and chemical film and paper products such as newspapers.

If perovskites can be made reliably using these scalable fabrication approaches, they have the potential for faster capacity expansion than silicon PV. Both of these processes are well established in other industries, so existing knowledge and supply chains can be leveraged to further reduce scaling costs and risk.

Additional barriers to commercialization are the potential environmental impacts of perovskite materials, which are primarily lead-based. As such, alternative materials are being studied to evaluate, reduce, mitigate, and potentially eliminate toxicity and environmental concerns.

TECHNOLOGY VALIDATION AND BANKABILITY

Validation, performance verification, and bankability—ensuring the willingness of financial institutions to finance a project or proposal at reasonable interest rates—are 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 confidence in long-term operational behavior.

Current testing protocols for solar PV devices were developed for the existing mainstream PV technologies. These involve indoor testing using protocols that could also accurately predict outdoor performance in silicon and CdTe solar cells, which degrade very differently than perovskite technologies. Objective, trusted validation using test protocols that can adequately screen for real-world failure modes is critical to boost confidence in perovskite technologies, which is necessary to enable investment in production scale-up and deployment. The rapidly changing material and device compositions of perovskite solar cells make this standardized validation particularly challenging and important.

SETO has funded the **Perovskite Photovoltaic Accelerator for Commercializing Technologies (PACT) Validation and Bankability Center** to address these challenges. PACT will conduct field and lab testing, develop and validate accelerated test protocols and energy yield models, and conduct technical and commercial bankability studies to improve our understanding and confidence in the real-world durability of perovskite PV technologies.

SETO has also developed performance targets to support commercialization pathways for perovskite PV based on the **Performance Targets for Perovskite Photovoltaic Research, Development, and Demonstration Programs** Request for

Information (RFI). These targets for efficiency, stability and replicability of perovskite PV devices can align research directions and goals, ensuring that future funding programs are relevant and accelerating technical and commercial development and de-risking of perovskite technologies.

SETO Perovskite R&D Funding

- SETO FY2021 Small Innovative Projects in Solar (SIPS)
- American-Made Challenges: Perovskite Startup Prize
- SETO FY2020 Perovskite Funding Program
- SETO FY2020 Photovoltaics
- SETO FY2020 Small Innovative Projects in Solar (SIPS)
- SETO FY2019 Photovoltaics
- SETO FY2018 Photovoltaics
- Photovoltaics Research and Development: Small Innovative Projects in Solar (PVRD-SIPS)
- Next Generation Photovoltaics 3