U.S. DEPARTMENT OF ENERGY

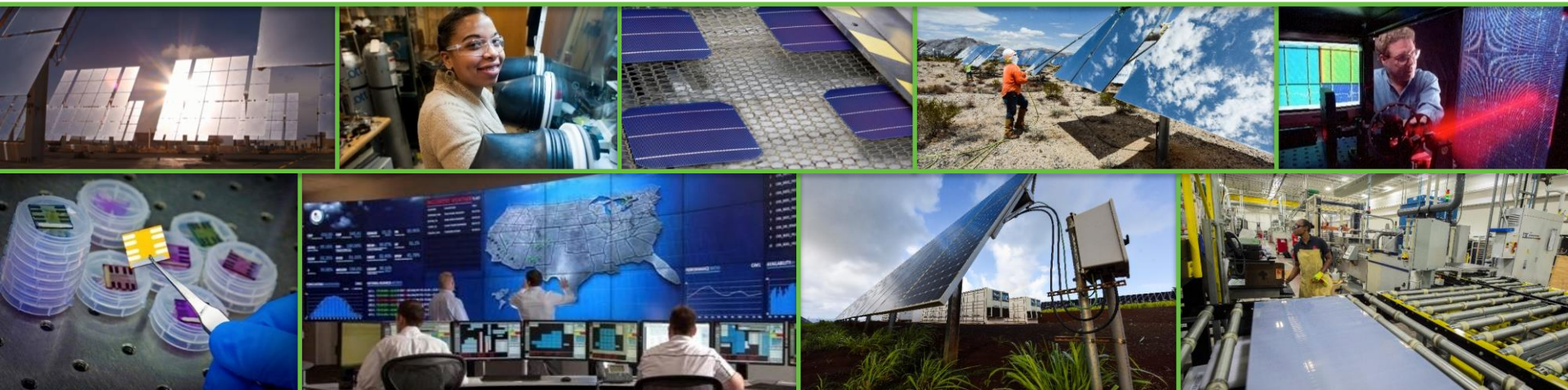
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Upcoming DOE Funding: Advancing U.S. Thin-Film Solar

U.S. Department of Energy (DOE)

Solar Energy Technologies Office (SETO)

July 10, 2023



Webinar Logistics

- Webinar recording and slides will be posted at bit.ly/thin-film-noi and on EERE Exchange
- Q&A protocol:
  - Use the Q&A tab to ask questions
    - Direct your question to All Panelists
  - DOE will take questions today and post the answers in 1-2 weeks on EERE Exchange and at bit.ly/thin-film-noi
    - Questions will be anonymized
  - DOE reserves the right to **not answer questions** for any reason
    - Questions beyond the scope of the NOI as determined by DOE will not be answered

Today's Presenters

Christie Ellis

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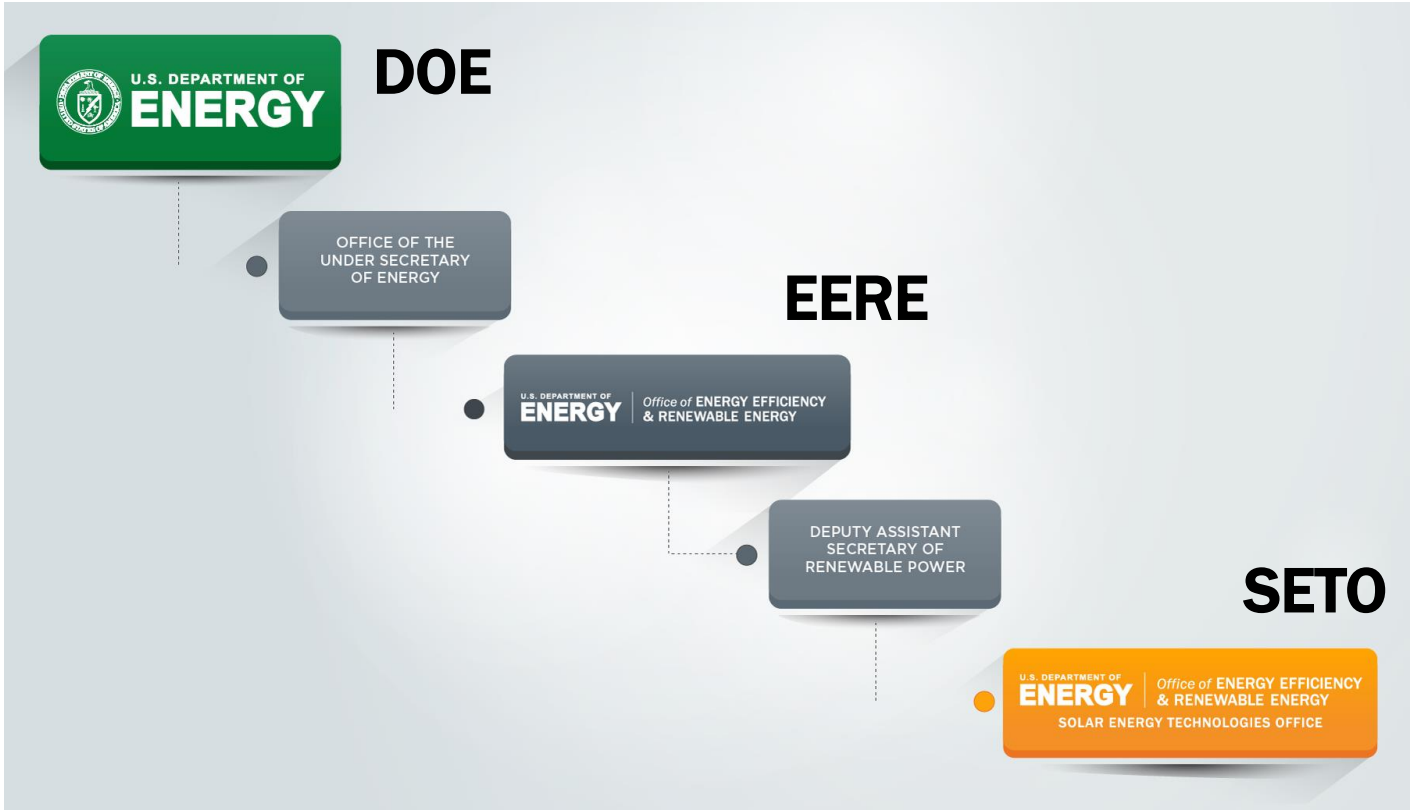
Solar Energy Technologies Office

Our mission is to accelerate the advancement and deployment of solar technology in support of an equitable transition to a decarbonized economy no later than 2050, starting with a decarbonized power sector by 2035.

To achieve this mission, solar energy must:

- Be affordable and accessible for all Americans
- Support the reliability, resilience, and security of the grid
- Create a sustainable industry that supports job growth, manufacturing, and the circular economy in a wide range of applications

Where Does SETO Fit Within the Energy Department?



SETO Research Areas

PHOTOVOLTAICS

CONCENTRATING SOLAR-THERMAL POWER

BALANCE OF SYSTEMS/ SOFT COST REDUCTION

SYSTEMS INTEGRATION

MANUFACTURING AND COMPETITIVENESS

Upcoming Funding for Perovskite and CdTe PV

Goal: Promote American leadership in thin-film PV technology and the domestic manufacture of thin-film PV modules.

SETO intends to release the **Advancing U.S. Thin-Film Solar** Funding Opportunity Announcement (FOA) in September 2023, which will provide **up to $36M** to accelerate two thin-film photovoltaic (PV) technologies:

- **Metal halide perovskite PV:** Industrial research and development projects
- **Cadmium telluride (CdTe) PV:** Industrial research, development, and demonstration projects

This notice of intent (NOI) allows potential applicants to identify and fill possible gaps in their capabilities before the FOA is released.

Disclaimer: Notice of Intent

- May issue a FOA as described herein, may issue a FOA that is significantly different than described herein, or may not issue a FOA at all

- NOI is issued so that interested parties are aware of the intention to issue this FOA in the near term

- All information is subject to change

Potential of Thin-Film PV Technologies

- U.S. has been a leader in the development of thin-film PV
- Potential advantages over the predominant PV technology, crystalline silicon (c-Si), such as:
  - less energy-intensive manufacturing
  - lower manufacturing capital expenditures
  - simpler supply chains
- Perovskite and CdTe PV face different major challenges based on their relative technological maturity to become competitive or stay competitive with c-Si PV

Topic Area 1:

Promoting Research & Development towards Industrial Manufacturing of Early-Stage Perovskite Tandem Photovoltaics

(PRIMES Perovskite Tandem PV)

Perovskite Background

- Perovskite PV's lab-scale power conversion efficiency (PCE) potential demonstrates promise for next-generation solar modules, especially tandem PV
- Some of the fastest-paced improvements in PCEs ever seen in an emerging PV technology:
  - Over 25% PCE in single-junction lab-scale cells
  - Over 33% PCE in tandem cells with silicon
- If proven to be scalable, durable, and cost-competitive, could contribute substantially towards long-term decarbonization and deployment goals
- Fundamental durability and manufacturing challenges must be solved before perovskites can substantially enter the market for grid-connected energy production

Perovskite Current Status

- Potential has accelerated the push to bring perovskite PV to the U.S. and international market
- Multiple announcements from companies to build and/or to begin operating >100 MW pilot manufacturing lines in the next 1-4 years
  - Many industry announcements have been delayed multiple times
- SETO believes perovskite may be on a trajectory to reach substantial market entry for grid-connected energy production **after 2030** (based on available data)
  - SETO has not seen a publicly available dataset for perovskite minimodules greater than 10 cm^2 in aperture area achieving efficiency ≥12% after 10 weeks of outdoor testing
- SETO believes additional R&D is needed to address reliability and performance-at-scale issues that remain unsolved to support future pilot manufacturing efforts

Perovskite Topic Overview

Goal: Put domestically manufactured perovskite tandem PV on the path to have substantial market uptake by 2030

Total Federal Funding	Up to $20M
Funding per Project	$3-20M
Cost Share	20%
Award Length	18-36 months

- Perovskite PV research and development (R&D) projects in an industrial setting to enable future commercialization by reaching specific thresholds of efficiency, durability, manufacturability, and economic viability
  - Durability remains the top priority—especially light and heat durability, and durability at the minimodule scale—without sacrificing efficiency
- Will not fund projects focused exclusively on manufacturing scale-up, but projects that, if successful, may enable pilot-scale manufacturing in the future
- Will focus on hybrid tandem devices that combine perovskite PV with another PV material (e.g., silicon or CdTe)

SETO Perovskite Performance Target Matrix

- Through a 2021 request for information (RFI), SETO developed a Performance Target Matrix to align the domestic industry on R&D metrics that would indicate readiness for manufacturing
  - Metrics on PCE, device area, durability testing, and sample size
- SETO seeks to support through this topic, the **achievement of the Performance Target Matrix by the end of 2026**
- Achievement is critical to enabling successful pilot manufacturing for perovskite PV
- 2026 timeline is critical for U.S. industry to compete with the incumbent industry and international entities
- Successful projects in this topic area will be able to achieve these metrics by the end of 2026
- Quantifiable targets reflect both technology progression and changing market dynamics
- SETO understands that substantial risk exists in achieving these targets and that support beyond the scope of this FOA may be needed
- Future needs will be assessed in alignment with these stated goals and pending future appropriations

SETO Perovskite Performance Target Matrix

Goal: Achieve these milestones by end of 2026

Aperture Area Power Conversation Efficiency (PCE)	Total Module Area	Durability	Sample Population Requirements
27% PCE (for hybrid tandems)	>=500 cm^2 with at least 4 interconnected cells	Pass IEC 61215 Module Quality Test (MQT) 10, 11, 13 and 21 and ISOS-L-2 at specified durations with <10% relative performance loss per test 6 months continuous outdoor testing with <3% relative degradation overall and <1% degradation in the final 3-month span	>1 kW total, at least 20 modules for outdoor testing

Industrial R&D and Scale-Up

- R&D necessary to reach the next stages of commercialization is inherently more resource intensive and best led by industry
- **Lead applicants will be restricted to for-profit entities**
  - Teaming with universities, national laboratories, and other supply chain or ecosystem partners is encouraged
- Academic, lab-scale advances on 0.1-1 cm^2 devices have been substantial
- Proving durability, efficiency, and reproducibility at modest scales of $\geq$100 cm^2 is a more significant barrier
- Projects should use industrially relevant processing equipment and large sample sizes to understand process variability at high confidence
- Use of structured experimentation methodology at statistically meaningful scale coupled with statistical analysis will be required, consistent with standard industrial R&D processes
- Projects solely focused on ramping up manufacturing processes to >1 m^2 size are not of interest at this time

Hybrid Tandem Devices

- Incumbent technologies like c-Si PV continue to improve in efficiency and lifetime while reducing cost
- Window of opportunity shrinking for a new single-junction absorber technology, regardless of the cost of the absorber layer
- Perovskite tandem PVs, paired with other established technologies such as c-Si, CdTe, CIGS, or organic PV, have demonstrated potential to achieve >30% PCE,
  - Exceeds the currently understood practical efficiency limits of single-junction c-Si PV.
- Hybrid tandems can leverage the large incumbent capacity base as opposed to competing against it
- Projects under this topic will advance hybrid perovskite tandem devices
- Projects on all-perovskite tandem or single-junction devices (that are not tandem compatible) are not of interest for this topic

Competitive Guidelines at Different Funding Levels

- Teams may propose projects at multiple levels of funding between $3 million-$20 million
- Guidelines describe a competitive application for a few example funding levels
- Can apply at levels between those mentioned
- Teams may excel in one or more of the areas identified but underperform in others
  - Teams that underperform in all areas should not expect a favorable review
- Communicating this information now so potential applicants can take advantage of the intervening time before a FOA is released to identify and fill possible gaps in their capabilities

Competitive Guidelines at Different Funding Levels

	$5M Federal Award	$10M Federal Award	$20M Federal Award
Performer	Team as a Whole	For-Profit Lead Applicant	For-Profit Lead Applicant
Team	No formal guideline beyond the basic applicant eligibility requirements	Project team has established and documented: • Experience in industrial R&D and manufacturing (preferably in the PV sector) • Clearly defined roles, responsibilities and decision-making processes • Business systems for supplier selection for capital equipment and critical raw materials • Experience in statistical experimental design and statistical procedures for qualifying processes and tools	In addition to $10M requirements, project team has established and documented: • Management team and senior leadership with significant experience bringing products from R&D to production in a manufacturing environment (preferably in the PV sector) • Modern project and program management practices informed through theory of constraints • Full traceability from incoming materials to outgoing products • Quality systems including statistical process control, statistical design of experiments, statistically informed raw and intermediate materials specifications

Competitive Guidelines at Different Funding Levels

	$5M Federal Award	$10M Federal Award	$20M Federal Award
Performer	Team as a Whole	For-Profit Lead Applicant	For-Profit Lead Applicant
Single Junction Cell Performance	Demonstrated small area cells (~0.1 cm^2 aperture area) with PCE ≥18% on devices with ≥1.6 eV band gap	ISO 17025 CTL (Certified Test Laboratory) verified performance of cells ≥ 1 cm^2 aperture area with PCE ≥18% on devices with ≥1.6 eV band gap	No formal guideline beyond achievement of $10M level
	OR	OR	
Tandem Cell Performance	Demonstrated small area cells (~0.1 cm^2 aperture area) with PCE ≥23%	ISO 17025 CTL verified performance of cells ≥ 1 cm^2 aperture area with PCE ≥24%	
Notes	Data must be provided to show that this performance can be readily reproduced with a mean PCE for ≥20 cells across ≥4 substrates produced across ≥2 days A rectangular opaque mask must be used to define the optically active aperture area.		

Competitive Guidelines at Different Funding Levels

	$5M Federal Award	$10M Federal Award	$20M Federal Award
Performer	Team as a Whole	For-Profit Lead Applicant	For-Profit Lead Applicant
Single Junction Minimodule Performance	No formal guideline	ISO 17025 CTL verified performance of minimodules ≥25 cm^2 aperture area with PCE ≥15%	No formal guideline
		OR	
Tandem Minimodule Performance		ISO 17025 CTL verified performance of minimodules ≥25 cm^2 aperture area with PCE >20%	ISO 17025 CTL verified PCE of the SETO RFI Performance Target Matrix for minimodules ≥25 cm^2 aperture area
Notes		Data must be provided to show that this performance can be readily reproduced with a mean PCE across a minimum of 10 separate devices produced across ≥2 days. A rectangular opaque mask must be used to define the optically active aperture area.	Data must be provided to show that this performance can be readily reproduced with a mean PCE across a minimum of 20 separate samples produced across ≥7 days. A rectangular opaque mask must be used to define the optically active aperture area.

Competitive Guidelines at Different Funding Levels

	$5M Federal Award	$10M Federal Award	$20M Federal Award
Performer	**Team as a Whole**	**For-Profit Lead Applicant**	**For-Profit Lead Applicant**
Durability Testing - Lab	Demonstrated combined heat and light stress testing: • ≥5 cells measured at V_{oc}, ≥5 cells measured at Maximum Power Point (MPP) subjected to ≥60°C for ≥1000 hours at ~1 sun illumination. • The drop in efficiency must be ≤20% relative at 1000 hours.	Demonstrated combined heat- and light-stress testing on encapsulated minimodules: • ≥5 devices measured at V_{oc}, ≥5 devices measured at Maximum Power Point (MPP) subjected to ≥60°C for ≥1000 hours at ~1 sun illumination. • The drop in efficiency must be ≤10% relative at 1000 hours.	Passed at least 4 of the 5 accelerated stress tests specified in the Performance Target Matrix (i.e., MQT 10, MQT 11, MQT 13, MQT 21, ISOS-L-2).
Durability Testing - Outdoor	No formal guideline	Devices on-sun at outdoor testing facilities (preferably with samples at PACT)	Demonstrated ≥3 months of outdoor field testing with <3% relative degradation (with minimodules on test at PACT[28] for ≥10 weeks) with ≥10 W of samples (≥20 minimodules).
Notes	• Cell starting performance and size for degradation testing must be greater than or equal to cell performance requirement. • Cells should be appropriately preconditioned using heat/light stabilization or dark soaking. • ≥10 cells should be from a single batch of production. • Cells may be encapsulated or unencapsulated in controlled environment.	• Minimodule starting performance and size for degradation testing must be greater than or equal to minimodule performance requirement. • Devices should be appropriately preconditioned using heat/light stabilization or dark soaking. • ≥10 minimodules should be from a single batch of production	• Minimodule starting performance and size for degradation testing must be greater than or equal to minimodule performance requirement.

Competitive Guidelines at Different Funding Levels

	$5M Federal Award	$10M Federal Award	$20M Federal Award
Performer	Team as a Whole	For-Profit Lead Applicant	For-Profit Lead Applicant
Fabrication Capability - Current	≥100 devices/week	≥100 minimodules/week (which should be from ≥25 substrates of ≥100 cm^2 area each)	≥500 minimodules/week (which should be from ≥100 substrates of ≥100 cm^2 area each)
Fabrication Capability - Future Plan	≥100 devices per week at ≥100 cm^2 aperture area	≥100 devices per week at ≥500 cm^2 aperture area	scale to 1-shift operation capable of producing ≥2000 devices per week at ≥500 cm^2 aperture area
Notes	The production capability listed is considered the peak capability and it is understood that teams will not typically operate at this level for multiple weeks		

Topic Area 2:

Improving the Market Potential of Advanced Cadmium Telluride Photovoltaics

(IMPAC$_d$T$_e$ PV)

CdTe Background

- CdTe PV is the leading domestically fabricated PV technology and the only thin-film technology significantly competing with c-Si PV
  - Successful high-volume manufacturing (nearly 9 GWdc produced globally in 2022)
  - Represents ~33% of all PV installed in the United States in 2022
  - Low embodied energy, lower temperature sensitivity, and established bankability
- Large-scale U.S. deployment of CdTe PV is anticipated to continue and accelerate
- Streamlined, rapid CdTe manufacturing process offers advantages over c-Si PV
  - Requires fewer unit processes than c-Si manufacturing – lower capital expenditures
  - 18.5% efficient CdTe module has about 36% of the embodied energy of a c-Si module
- U.S. manufactured CdTe modules have a domestic content of 60-90%, while most components of U.S. manufactured c-Si silicon modules are currently imported
- U.S. CdTe manufacturing capacity is rapidly increasing

CdTe Current Status

- U.S. in a unique position with two significantly different PV technologies being deployed at scale (c-Si and CdTe) with impacts of the Inflation Reduction Act and recent announcements in CdTe PV manufacturing capacity expansion will put the
- CdTe PV technology—tools, processes, materials, metrology at each step in the supply chain—will require continued innovation to stay competitive with c-Si
- U.S. PV system installation, inspection, operations, and maintenance industry must innovate to adapt to the unique aspects of CdTe PV systems
- Unique domestic need to assess quality and field performance at time of installation and throughout the system's lifetime since most globally produced CdTe PV is installed in the U.S.
- Many of the current tools for assessing PV reliability were designed for c-Si
- Could be optimized to gather data for CdTe PV systems, or unique approaches to assess CdTe PV arrays could be developed

CdTe Topic Overview

Goal: Drive advances along the entire supply chain for domestically manufactured and deployed cadmium telluride (CdTe) thin-film PV

Total Federal Funding	Up to $16M
Funding per Project	$1-15M
Cost Share	20-50%
Award Length	12-36 months

- Domestic research, development, demonstration, and commercialization projects across the CdTe PV materials, equipment, installation, and performance monitoring supply chain
- Innovations in the manufacturing supply chain that improve throughput, performance, energy intensity and production costs for unit process and integrated manufacturing while maintaining quality and reliability
- Innovations to enhance the performance, reliability, and technical aspects of bankability of CdTe PV systems
- Lead applicants restricted to for-profit entities, although collaborations with universities, national laboratories, and other companies are encouraged

CdTe Target Areas

- Topic solicits applications that can lead to improvements in performance, cost reduction, and/or energy intensity reduction at each step in the CdTe supply chain (from manufacturing, to deployment, to decommissioning and recycling), in areas such as:
  - metrology
  - lifetime improvements
  - quality control
  - demonstration of energy yield
  - performance monitoring
  - recycling at end-of-life
  - equipment design
  - raw materials extraction (especially for tellurium, a critical mineral for CdTe manufacturing)
  - refining and compounding
  - glass superstrate and back glass
  - module recycling and resource recovery
  - tools and processes used in CdTe module fabrication, measurement, and testing, including automation

R&D versus Demonstration-Focused Projects

- Topic is divided into two categories: R&D and demonstration.
- Applications proposing less than $3M in federal funding are expected to consist primarily of R&D activities and may have lower cost-share requirements (20%)
- Projects requesting $3-15M in federal funding are expected to occur at the demonstration scale and are expected to carry 50% cost share
- It is possible for entities to propose a mix of these activities

CdTe R&D-focused Projects

R&D-focused projects should address one or more of the following goals:

- Monitoring fielded performance/energy yield of CdTe PV systems through innovations in metrology and instrumentation
- Improving metrology for CdTe related processes and materials
- Reducing cost and resource intensity of domestically produced CdTe PV modules;
- Improving manufacturing throughput and or reducing manufacturing cost for CdTe raw materials, intermediates, or modules
- Innovating CdTe technology across the supply chain, including processing, measurement, and Quality Assurance (QA)/Quality Control (QC)
- Increasing the fielded lifetime and/or energy yield of CdTe PV modules and reducing the lifecycle costs of CdTe PV systems
- Expanding the domestic supply chain for CdTe PV material production, especially the availability of tellurium for module manufacturers, including reclamation of materials from end-of-life modules
- Improving the viability of tandem modules where CdTe is one of the active layers
- Improving the recycling process for CdTe PV modules

CdTe Demonstration-Focused Projects

Applicants proposing demonstration activities should have access to facilities necessary to carry out work at this scale and experience with projects with similar demands and complexity

Demonstration projects may address any of the goals for R&D projects, and should include one or more of the following activities:

- New CdTe hardware component(s) or novel system architectures in robust, commercially relevant pilot tests
- Methods and instrumentation to monitor of fielded performance of CdTe PV at scale
- High-volume or high-throughput manufacturing processes for CdTe supply-chain components, processes, tools, metrology, and input materials that reduce cost, energy requirements, and greenhouse gas emissions, and that can be manufactured competitively in the United States
- Improved tellurium resource recovery from metal refining operations at scale
- Production of enough CdTe modules for statistically robust field testing and validation
- Demonstration of recycling and reclamation of CdTe modules and materials used to manufacture CdTe modules at scale

Next Steps for Interested Applicants

Teaming List

- Strongly encourage for-profit applicants to form partnerships with academia, national laboratories, other industry members, supply chain partners, and equipment developers
- DOE is compiling a “Teaming Partner List” to facilitate the formation of project teams for this FOA
- Allows organizations to express their interest in joining a project team to other applicants and to explore potential partnerships
- Updates to the list will be available in the EERE Exchange website
- Go to EERE Exchange to add your organization to the list

Next Steps

- Read the full NOI and find instructions at bit.ly/thin-film-noi
  - Register with EERE Exchange, SAM, FedConnect, Grants.gov
  - Join teaming list
- Put any questions in the chat
  - Answers will be posted on EERE Exchange and on NOI site in 1-2 weeks
- Sign up for the SETO newsletter at energy.gov/solar-newsletter
- Sign up for EERE funding notice list at energy.gov/eere/funding/eere-funding-opportunities

Interested in Joining Us?

Join our team. Design national R&D strategies across:

- Photovoltaics
- Systems Integration
- Manufacturing and Competitiveness
- Concentrating Solar-Thermal Power
- Soft Costs (Balance of Systems)

Email ops.solar@ee.doe.gov for more information.

ORISE Science & Technology Policy Fellowship

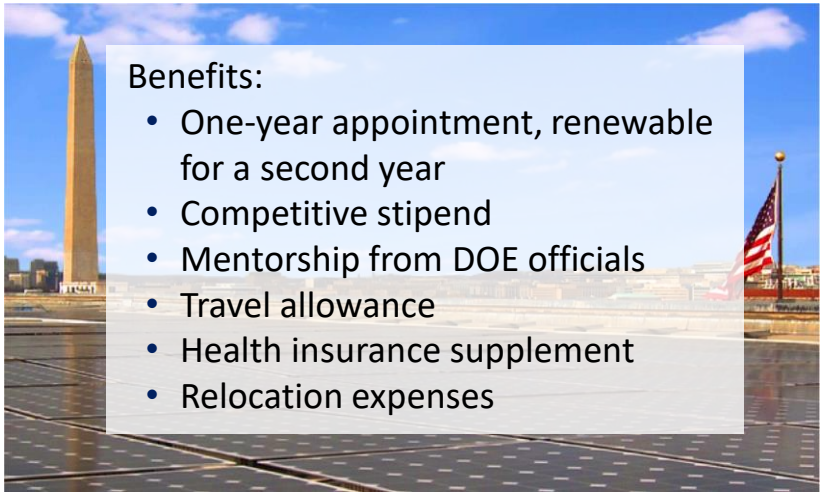
Develop leadership skills in science and technology policy by designing and implementing national research and development (R&D) programs

Strategic Areas:

- Photovoltaic technologies
- Concentrating solar-thermal power technologies
- Grid systems integration technologies
- Behavioral science, strategic analysis, and technical assistance
- Manufacturing and technology transfer
- Environmental justice and finance
- Communications and stakeholder engagement

Eligibility:

Open to physical, natural, and social scientists, engineers, and entrepreneurs with bachelor's, master's, or doctoral degrees, and established professionals with post-degree experience. Must be a U.S. citizen or have Permanent Resident (Green Card) status.



Apply by July 15

VISIT: bit.ly/SETO-Fellowships • EMAIL: DOE-RPP@orau.org

Thank You for Attending!

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