DRAFT BROAD AGENCY ANNOUNCEMENT: IARPA-BAA-XX-XX

SOLSTICE Program

List of Abbreviations

AM0	Air Mass 0 solar spectrum
AM1.5G	Air Mass 1.5 global solar spectrum
BAA	Broad Agency Announcement
COTS	Commercial Off The Shelf
DoD	Department of Defense
EHY	Energy Harvesting Yield
IARPA	Intelligence Advanced Research Projects Activity
IC	Intelligence Community
I_{mp}	Current at maximum power point
I_{sc}	Short circuit current
I-V	Current-Voltage
kWh	Kilowatt-hours
P_{mp}	Maximum Power Point
POC	Proof of Concept
PPS	Prototype Power System
PST	Power System Testbed
PV	Photovoltaic
SOA	State of the Art
SOLSTICE	Superior Options for Long-life Solar Technologies with Impressive Conversion Efficiencies
STP	Standard Temperature and Pressure
T&E	Test & Evaluation
T&E	Test and Evaluation
TVAC	Thermal-vacuum
VCM	Volatile Condensable Materials
V_{mp}	Voltage at maximum power point
V_{oc}	Open circuit voltage

SECTION 1: TECHNICAL PROGRAM DESCRIPTION

The Intelligence Advanced Research Projects Activity (IARPA) often selects its research efforts through the Broad Agency Announcement (BAA) process. The use of a BAA solicitation allows a wide range of innovative ideas and concepts. The BAA will appear on https://sam.gov/and will be linked from the IARPA website at https://www.iarpa.gov/. The following information is for those wishing to respond to this Program BAA.

This BAA (IARPA-BAA-XX-XX) is for the Superior Options for Long-life Solar Technologies with Impressive Conversion Efficiencies (SOLSTICE) program. IARPA is seeking innovative power solutions to support Intelligence Community (IC) applications in the space (Track 1) and terrestrial surface (Track 2) environments. SOLSTICE is envisioned to be a 4-year effort, beginning approximately early 2025 and extending through early 2029.

1.A. Program Overview

The Intelligence Community routinely relies upon a variety of stand-alone electronic assets deployed in remote locations. The power systems onboard these devices are essential to ensure mission success. However, remote devices are often subjected to challenging environmental conditions in space and on the earth (land or water) that degrade or limit power system performance. Since there is typically limited or no ability to service these devices in the field, a significant overdesign of power systems is usually necessary to ensure continuity of mission operations. This overdesign adds weight, volume, and deployment complexity that may “squeeze-out” payload components that would otherwise be valuable to have. Some desired higher-power payloads may simply be impractical to implement or must be duty-cycled due to power system limitations.

Solar photovoltaic (PV) energy conversion technologies have a long heritage of supporting many remote platforms in all the aforementioned environments. PV cells and modules of different efficiency levels can be tailored for a variety of settings and in a variety of form factors. These are largely commoditized products used across the IC, DoD, and commercial applications alike. Yet despite the plethora of available options, power and energy needs onboard remote platforms continue to grow. Simply adding additional solar modules to address these needs adds more bulk to the system that complicates transportation, deployment, and/or unobtrusive operation in the target environment. High efficiency (multijunction) solar cell systems, currently used almost exclusively for space, are available from a small number of suppliers and can achieve high conversion efficiencies (~30-33%) at the cell level. However, once typical operating conditions (i.e. varying irradiance, temperature), power conversion, and system level losses are accounted for, the realized time-weighted efficiency is substantially reduced, limiting available power/energy. Other potential high-power technologies, such as fuel cells and radioisotope thermoelectric generators (RTGs), may be useful in some scenarios, but lack some of solar PV’s key advantages, namely, high modularity, low weight, low noise, lower thermal signature, safety, and predictable failure modes. The IC needs power systems with a) high power density per unit of collection area, b) durability against environmental stressors, c) obscuration from or resilience against human-made physical threats, and d) high energy harvesting yield (EHY) over a mission lifetime .

The SOLSTICE program will develop novel power systems that use solar energy as an input (alone or in tandem with other sources available in the surrounding environment) for application in space (Track 1) or terrestrial surface environments (Track 2). While there will be significant component development as part of SOLSTICE, performance at the system level will remain the key focus of each project. SOLSTICE seeks to facilitate cross-collaboration among power system component R&D teams to enable a significant leap in power density and mission energy availability to remote assets deploying SOLSTICE technology. Objectives of the SOLSTICE program include developing power systems with significantly increased overall efficiency, high power density, high mission energy harvesting yield (EHY), long mission lifetimes, and robustness to the challenging conditions presented within each target environment. Approaches that minimize the vulnerabilities and limitations in component supply chains are also highly encouraged. Detailed information about specific goals, objectives, metrics, and milestones can be found in this BAA.

The SOLSTICE program will be structured into three phases. Phase 1 ("Proof of Concept (POC) Development") will last 18 months in which teams will demonstrate proofs of concept for novel high-risk components of their proposed system design. Performance of these POC components will be fed into system-level models developed by the Performer and transferred to the SOLSTICE Testing and Evaluation (T&E) partner for evaluation and input into standard orbital or terrestrial performance models that will be used across the SOLSTICE program. Phase I deliverables will include test articles of the novel components as well as conceptual system designs and modeling/calculations extrapolating performance across the set of conditions possible in the target environment(s). Phase 2 ("Prototype Demonstration") will last 18 months in which teams will assemble a first-generation technology demonstration prototype power system (PPS) combining components proposed and approved by IARPA in their end of Phase I design plans. Phase 2 will include several PPS test articles (defined in Section 1.D) delivered to the SOLSTICE T&E partners for performance evaluation. Performance metrics for these PPSs (see Section 1.E of this BAA) must be met or exceeded to proceed to the next Phase. Phase 3 ("Scalability and Durability Assessment") will last 12 months. Phase 3 Performers will iterate their PPS design based on Phase 2 learnings and demonstrate a higher-power-output PPS that may require deployment of greater collection area. These PPS Test Articles will also undergo preliminary durability testing to assess reliability in the target environments. The goal of the program is technology demonstrating very high efficiency and well-performing PPSs that show viability for transition to IC partners for continued development.

1.B. Technical Approaches

Power systems proposed to the SOLSTICE program will need to have the following properties (see Section 1.E. for specific metrics):

- High time-weighted system efficiency, resulting in high mission lifetime energy harvesting yield (kWh)
- High collection area power density (W/m^2)
- Minimal power density reduction (from both environmental conditions and single damage events) over time
- Capable of autonomous deployment from realistic vehicles for the target environment
- Minimal surface reflection and thermal signature

In space environments, ten-year lifetimes are assumed with deployment achieved from an existing launch vehicle. In terrestrial environments, 3-year lifetimes are assumed with deployment occurring autonomously onto land or water from an air- or water-craft.

To achieve the goals and metrics of the SOLSTICE program (detailed in Section 1.E of this BAA), Offerors will leverage recent and emerging technologies in, for example, solar cells and hybrid power-generation approaches, optics, thermal management, power electronics, and other enabling components to yield power system solutions with unprecedented performance. Concepts could include new 1-sun PV devices, (micro)concentrated solar PV, hybridization of PV with alternative energy conversion or storage devices (e.g. thermoelectric, thermoradiative), innovative power electronics (e.g. photonic transformers, highly discretized power optimization), tunable/adaptive optical materials (thermochromics, electrochromics, metalens optics), new thermal management/storage strategies (e.g. phase change materials, heat pipes, thermal valves), and other solutions that optimize the conversion of sunlight and other energy capturable from the local environment into electricity. System designs may be proposed that do not use solar energy, but must still meet all the performance metrics described below along with other limitations (see section 1.C.4 below). Offerors may propose any combination of innovative approaches and/or components to realistically achieve the metrics of the program. Novel approaches towards the design of materials, components, and/or systems (e.g. potentially leveraging machine-learning, artificial intelligence algorithms) are encouraged. Multidisciplinary teams are expected to achieve the ultimate systems-level optimization sought in the SOLSTICE program. While component development is a key part of earlier phases of the Program, exclusive focus on component technology in the absence of a system level approach toward meeting the SOLSTICE program targets is out of scope. Innovations may involve, but are not limited to, the following areas:

Solar Cells and Hybrid Power-generation Structures

Solutions may leverage novel photovoltaic and other photoresponsive materials, cell architectures, and other supporting components to maximize the energy conversion and collection density from the light aperture area and other portions of the device. Solar cells could be designed for 1-sun or part of a concentrated solar system. Innovations in multijunction and tandem solar cell photoactive materials, device structures, contacts, substrates, coatings, and encapsulation may contribute to increased overall efficiency, durability, and/or manufacturability. New materials or approaches to capture and convert unutilized or poorly converted portions of the solar spectrum to contribute more towards the overall cell, module, or system efficiency could also help deliver the performance required to meet the SOLSTICE program metrics. These approaches could be synergistic with some Thermal Management and Power Electronics solutions (see subsections below) to realize higher power or energy densities. Other approaches that leverage conditions of the local environment to convert or store additional energy may boost the mission lifetime energy harvesting yield. New fabrication methods for components and structures may produce higher performance, greater yield, and/or lower costs than existing methods.

Optics

The efficient capture and direction of light is an essential part of the photon-to-current collection efficiency, as is the protection of sensitive materials and systems that carry out the photoconversion. Concentrating optics is a known way to improve solar cell power density that has thus far proven difficult to implement practically due in part to the optical efficiency limitations, sun-pointing angle of acceptance restrictions, thermal management, cost, and deployment challenges that are imposed. Simpler 1-sun PV has generally been preferred over macro-scale concentrating optics. However, new approaches to deliver a modest amount of concentrated light to solar absorbers (potentially including micro-concentrators, adaptive optics, spectrum-splitting optics, non-mechanical sun tracking) with low-profile designs that can achieve good sun tracking and be deployable may present options that can achieve the SOLSTICE targets. Robust coatings and protective layers that can maintain high optical efficiency of light collection over time while protecting against environmental stressors (e.g. proton or electron radiation in space, moisture and soiling/abrasion on the earth surface) could support the lifetime energy harvesting yield of power systems in SOLSTICE.

Thermal Management

Approaches to properly manage, use, store, and/or reject heat will be key to optimizing long-term stability, improving overall performance, and minimizing detectability. Novel components introduced in other parts of a SOLSTICE system may cause higher heat gain (e.g. concentrators) which may be able to reduce power needs elsewhere on a spacecraft or terrestrial platform. Approaches that can convert waste heat into useful work/energy could add to the overall annual energy harvesting yield and power density of the power system. These approaches could also reduce the amount of time or the intensity of "dark cycles" of the power system when sunlight is not available which can place greater demands on the energy storage system. Macro or micro-scale thermoelectric devices, thermoradiative cells, and thermal energy storage components may offer some opportunities. Coatings, substrates, and other materials that can adapt to changing thermal conditions (e.g. thermochromics) or other stimuli could aid with temporal control of heat flow towards more optimal performance of components and the system as a whole.

Power Electronics

Solutions may leverage a number of potential strategies to convert energy into electricity useable by the remote platform, including traditional centrally-organized and highly distributed (i.e. on-wafer cell/subcell-level) power electronic topologies. Strategies that improve resilience to environmental and human-created stressors and/or single-event failure modes in the power electronics could lead to higher overall lifetime energy harvesting yields and improve the survivability of key power-conversion components, even if portions of the power-conversion system are beyond recovery. These solutions may also result in efficiency improvements in aggregate in circumstances when light absorption is non-optimal (e.g. partial array shading, damage, soiling, changing incidence angle) or when other inhomogeneities of the energy collection components are present (e.g. variable temperature, single-cell failures from debris impacts). While electrochemical energy storage development (i.e. batteries) is out of scope, approaches to better manage the flow of energy (electrical, thermal, or otherwise), transiently store energy, or otherwise support the battery management system could yield overall efficiency improvements.

Novel Deployment and Survivability Approaches

New approaches toward packing/deploying solar arrays, optics, and other portions of the power system may result in greater stowed volumetric power densities that can achieve the SOLSTICE targets. Methods to stow and protect the aperture area during threatening periods from environmental and/or human-made physical threats could help maximize the lifetime energy yield of the power system. Autonomous or remotely triggered restorative procedures that repair or regenerate damaged or degraded components could prolong the useful life and mitigate risk. Materials that "self-heal" or otherwise offer greater resilience to the stressors of their environment could also offer promise.

The above-stated components and approaches are examples of the types of innovations sought in this BAA, but potential Offerors should not feel limited to these categories. Any component level or system level innovation or approaches that will aid in reaching the SOLSTICE program targets will be considered. While solutions proposed to SOLSTICE may include many of the aforementioned innovative components to achieve higher power density and lifetime energy harvesting yield, consideration must be made towards the deployment challenges that may be imposed by novel approaches in the target environment. Power systems destined for space must be able to pack within a launch vehicle, survive launch conditions, and be reliably deployed autonomously once in space. Similarly, remote systems deployed on land or water must start in a reduced-volume packed state and successfully deploy autonomously once they reach their target location.

Energy storage is an integral part of a remote power system and SOLSTICE will largely leverage established energy storage component technology (e.g. batteries, supercapacitors, thermal energy storage). Proposed energy storage components should generally be commercially available or capable of being fabricated via already demonstrated reproducible protocols. However, novel approaches to orient, structure, allocate, manage, and/or control the energy storage in the context of an overarching SOLSTICE power system design can be proposed.

1.C. Program Description and Structure

1.C.1. Program Goals

The SOLSTICE program will pursue two research tracks that target power system development for application in an earth-orbital environment, such as satellite systems (Track 1), and land or water-based application, such as land-based or buoy-mounted devices (Track 2). The power system solutions to be developed could be used for a wide variety of applications in each target environment that need consistently high-power delivery to payloads; no particular form factor is specified nor are any particular devices to be powered envisaged. Offerors may propose to a single track, to both tracks separately, or to both tracks with a single power system solution. Offerors who propose to both tracks shall be required to submit test articles in the numbers specified in

Section 1.D “Testing & Evaluation” to support separate testing and evaluation (T&E) for each track.

The overall goals of the two tracks are as follows:

Track 1: Space-based Energy Conversion Systems

Track 1 aims to demonstrate the following improvements over state-of-the-art PV energy conversion systems deployed in space:

1. Substantially higher power density (W/m^2) for a given solar aperture area under AM0 incident sunlight[1];
2. High time-averaged system efficiency, resulting in a substantially higher lifetime energy harvesting yield (kWh) over a simulated **10-year** mission compared to a SOA system;
3. Significant retention of power density over a simulated **10-year** mission lifetime;
4. Ability to stow the system at high volumetric power density (kW/m^3);
5. Retention of most power output following a physical and/or high flux irradiation damage incident;
6. Minimal surface reflection and thermal signature;
7. High specific power (W/kg);
8. Ability to survive autonomous launch/deployment;
9. Comparable cost to 1-sun multijunction space PV systems.

Track 2: Terrestrial surface-based Energy Conversion Systems

Track 2 aims to demonstrate the following improvements over state-of-the-art PV power systems deployed in remote terrestrial surface locations:

1. Substantially higher power density (W/m^2) for a given solar aperture area under AM1.5G incident sunlight[2];
2. High time-averaged system efficiency, resulting in a substantially higher lifetime energy harvesting yield (kWh) over a simulated **3-year** mission compared to a SOA system;
3. Significant retention of power density over a simulated **3-year** mission lifetime;
4. Ability to stow the system at high volumetric power density (kW/m^3)
5. Retention of most power output following a physical and/or high flux irradiation damage incident;
6. Minimal surface reflection and thermal signature;
7. High specific power (W/kg);
8. Ability to survive autonomous deployment from an air or water craft;
9. Comparable cost to notional 1-sun multijunction terrestrial PV systems.

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[1] AM0 = Air Mass 0 average spectral irradiance typically experienced in an earth-orbital environment with 1366 W/m^2 total incident power

[2] AM1.5G = Air Mass 1.5 global standard spectral irradiance typical at the earth surface with 1000 W/m^2 total incident power

Both Track 1 and Track 2 system solutions must demonstrate performance under simulated environmental conditions, as well as achievement of other metrics specified in Section 1.E Program Metrics.

1.C.2. Program Structure

The SOLSTICE program will proceed in three phases as follows:

Phase 1 (18 months) Proof of Concept Development (POC)

The objective of Phase 1 "Proof of Concept Development" (POC) is to demonstrate new materials, devices, and other component technologies for power systems that, with further development and integration into a prototype power system, could allow the system to meet the Track 1 and/or Track 2 performance metrics shown in Section 1.E. of this BAA. For Phase 1, demonstration deliverables must be "self-contained", meaning they must allow IARPA to perform independent testing and evaluation (T&E) to measure performance, under solar-simulated light or other specified conditions, towards the Program Metrics set for Phase 1. It is anticipated that these demonstrations will incorporate commercial off-the-shelf (COTS) parts alongside novel components under development by the Performer team.

In addition to delivering proof of concept solutions for T&E, Performers must deliver preliminary design documents and modeling and/or other calculations to demonstrate that the novel components, when realized as part of a power system prototype design (intended for development later in the Program), can be expected to meet all Phase 1 metrics. The mathematical models must describe how the new components will contribute to achieving the Program Metrics in Phase 1 as part of the power system planned for Phase 2, detailing key assumptions and extrapolations, taking into account effects not replicable with the test articles submitted to the T&E partners. (e.g. thermal management, lower losses due to higher system voltages, etc.)

At the conclusion of Phase 1, Performers must also make a compelling argument, supported by extrapolations from data and modeling, that their Phase 1 proof of concept and future design approach can reasonably be expected to meet Phase 3 metrics with further development by the end of the program.

Phase 2 (18 months) Prototype Demonstration

In Phase 2, Performers will improve upon materials, devices, and designs developed in Phase 1 to fabricate a fully integrated prototype power system (PPS). Performers will assemble standardized test platforms, Power System Testbeds (PSTs), based upon specifications received from the T&E team and then integrate their novel and COTS power system components to form a PPS. Preliminary PST characteristics are described in the section 1.D introduction. The principal Deliverables for Phase 2 will be several PPSs from each Performer for T&E. PPSs will undergo substantial performance characterization under a range of operating conditions anticipated in target environment(s). Performance will be compared to reference PPSs assembled by the T&E team using best-available COTS components. Experimentally derived performance parameters will be fed into standardized models assembled by the T&E team to predict energy harvesting yield (EHY). In addition to the PPSs, Performers must deliver updated component-level and system models/simulations that will be compared with T&E modeling/simulation. Performers must also develop a strategy and deliver a physical demonstration of how their power system will scale beyond the Phase 2 PPS system size to include a larger aperture area. Performers must provide a clear description of how the power system will mature to meet the required metrics for Phase 3 of the program. PPSs have no specific voltage, current, or mass requirement, provided the integrated components fit within the volume of the PST form factor and meet the interface requirements as defined by the T&E team. PPS units should perform safely under the T&E testing protocols without dangerous incident.

Phase 3 (12 months) Scalability and Durability Assessment

In Phase 3, Performers will refine and scale their power systems to meet Phase 3 metrics. Performers will continue to leverage the standardized PST form factor used in Phase 2 and update their PPS design with improved components and/or approaches to achieve the end of Phase 3 metrics. These PPSs will be sent to the T&E team for performance and durability evaluation. Durability tests will include testing against potential failure modes and conditions that could be expected in the target environment. PPS units should perform safely under the T&E testing protocols without dangerous incident.

1.C.3. Team Expertise

Collaborative efforts and teaming among Offerors are highly encouraged. It is anticipated that teams will be multidisciplinary, leveraging expertise, capabilities, and innovations under development from a range of entities. IARPA anticipates that Offeror teams may include, but are not limited to, expertise in the following technical areas. Expertise in all these disciplines is not a selection criterion.

- Materials science/engineering or chemistry
- Electrical engineering
- Optics/Optical engineering
- Mechanical engineering
- Thermal science/engineering
- Radiation physics
- Condensed matter physics
- Theoretical chemistry/physics and modeling
- Systems Engineering
- Engineering co-design/development
- Multi-physics modeling/simulation
- Machine-learning (ML)/artificial intelligence (AI) aided design
- Corrosion

1.C.4. Out-of-Scope Research Areas

The following areas of research are out of scope for the SOLSTICE program:

- Component development that cannot be independently tested and evaluated to assess contribution toward the program metrics.
- Development of novel electrochemical or thermal energy storage chemistries

- Solutions that employ radioactive materials as part of components or would integrate radioactive materials as part of a system-level design.
- Approaches that propose, or are likely to result in, only incremental improvements over the current state-of-the-art.
- Approaches with significant limitations on operating conditions or operational parameters.
- Approaches that are incompatible with remote, unattended operation.
- Approaches that cannot be packaged for safety.
- Development of component technology that is not integral to the operation of the power system required for the Offeror's approach.
- Solutions that cannot be made sufficiently robust for use in the target application environments for each respective track.
- Research that does not have strong theoretical and experimental foundations or plausible scientific support for the Offeror's claims.

1.D. Testing and Evaluation (T&E)

All deliverables will be subjected to independent, objective T&E that will verify progress toward achieving program objectives at defined points during the program. Achievement of program metrics at these defined points may be a condition for continued participation in the SOLSTICE program.

Deliverables will be tested as received and must contain suitable electrical and mechanical interface points as described in the T&E Procedures Manual. Power systems must deliver power immediately upon excitation. Performers must provide the maximum power point (W_{mp}) to the T&E team for each test article provided in the form of a current-voltage sweep plot at 298 K (hereafter referred to as an I-V sweep) clearly showing W_{mp}, open circuit voltage (V_{OC}), and short circuit current (I_{SC}). Safe operating ranges for current and voltage must be specified to the T&E team.

There will be two rounds of T&E in each of Phase 1 and 2 of the SOLSTICE program as shown in the Program Milestone, Deliverables and Testing Schedule in Table 5 in Section 1.F.3. of this BAA. Phase 3 will have one round of T&E as described in the schedule.

The following is a notional description of testing protocols planned for the SOLSTICE program. Final testing protocols will be provided at program kickoff as part of the Test & Evaluation Procedures Manual (T&E Procedures Manual) and are subject to revision throughout the program. Performers are expected to conduct their own T&E of their power solutions continually throughout the program to measure progress toward achieving program metrics. Proposals shall describe how the Offeror plans to conduct their own T&E in preparation for the independent Government T&E of deliverables described below. If at any point during test article assessment the T&E team (at their sole discretion) deems further testing of a test article to be unsafe for the test equipment or T&E personnel, the testing of that test article will cease immediately and the data/results for that test article will be interpreted as captured up to that point and no further. Performers may expect up to three months of time after test articles are delivered before independent Government results are available. Performers will be responsible for transportation of deliverables to designated T&E sites in compliance with all applicable laws and regulations.

For Phase 1 (Proof of Concept), each Performer shall deliver at least one (1) POC test article at the first T&E event and at least three (3) POC test articles at the second T&E event, consisting of innovative components integrated as necessary with COTS components to demonstrate measurable performance sufficient to model and extrapolate to the system-level metrics outlined in Table 5 in Section 1.F.3. Offerors shall specify the form factor of their test articles for this Phase and the calculations they recommend to extrapolate performance to a power system level. Unless an energy storage medium is essential to the innovation(s) being demonstrated, proof of concept test articles are not expected to have an integrated battery or charge controller.

For Phase 2 (Prototype Demonstration), each Performer shall deliver one (1) Prototype Power System (PPS) test article for the first T&E event and three (3) PPS test articles for the second T&E event. Each PPS will integrate novel component(s) and system-level approaches consistent with the proposed system utilizing the standardized Power System Testbed (PST) form-factor that meets the requirements specified by the T&E team. Specifics of the PST electrical and mechanical interface will be finalized by the SOLSTICE kickoff meeting, but the general PST form factor includes the following requirements: 1) ~10 cm x ~20 cm x 10 cm body dimensions (i.e. similar to a 2U cubesat) with open internal volume for integrating components, 2) rechargeable electrical energy storage medium, 3) standard attachment points for hardware and electrical integration with T&E partner equipment. Performer PPSs integrated into the standard PST architecture will be shipped to the T&E partners for evaluation at two timepoints during Phase 2 and must be transportable by common shipping carriers.

For Phase 3 (Scalability and Durability Assessment), each Performer shall deliver two (2) PPS test articles integrated into the same PST body design used during Phase 2. Since Phase 3 PPSs could deploy beyond the body of the PST, Offerors must specify the intended size of their prototype at this phase. Any deployment beyond the body of the PPS must be contained within a volume of 4U attached outside the 2U of the PST body in any contiguous or non-contiguous arrangement (i.e. maximum total of 6U volume for body+deployed volume; 20 cm x 10 cm x 10 cm body + 4 units of 10 cm x 10 cm x 10 cm attached in any contiguous or non-contiguous arrangement outside the body). PPSs will be shipped to the T&E partners for evaluation during Phase 3 and must be transportable by common shipping carriers.

The schedule of deliverables and T&E events can be found in the Program Milestone, Deliverables and Testing Schedule in Table 5 in Section 1.F.3. of this BAA. In each T&E round, the delivered test articles will be tested against the performance metrics listed in Table 3 (Track 1) and Table 4 (Track 2) in Section 1.E. of this BAA. If there are testing considerations specific to an Offeror's solution that may be incompatible with the notional testing protocols described herein, these must be described in the Offeror's proposal. The Program Manager will release a subset of the T&E data to the Performer teams; some test articles may be returned to Performers, but for planning purposes there should be no expectation of return of the test articles following delivery to the T&E teams.

Characterization of power systems (components in Phase 1 or PPSs in Phase 2 and 3) will generally be conducted under solar-simulated light and a range of environmental conditions (outlined below) with output monitored via attachment of the output terminals to an electronic load simulator to test the device under operation. When possible, current-voltage (I-V) sweeps will be taken from components or combinations of components for troubleshooting or providing inputs to modeling. Performers will be expected to provide a range of safe current and voltage operating points for their submitted test articles. Current, voltage, time, derived electrical parameters (using current, voltage, and/or time), and temperature will be recorded for each power system tested. Temperatures will be measured by sensors attached to the test articles in positions chosen by the T&E team at their sole discretion. Test Articles submitted for Phase 1 testing will be assessed at room temperature and pressure under AM0 (Track 1) or AM1.5G (Track 2) solar simulated irradiance, as appropriate. By Phase 2 T&E events, Performers will be expected to have developed and integrated a system to appropriately manage thermal loads on PPSs to maintain consistent operation in the test environment. Performers must be prepared to discuss their safety plan for 1) material encapsulation, and 2) thermal management with the T&E team by the beginning of Phase 2 to assess risks associated with planned testing during the Phase 2 and 3 T&E events. At the T&E team's sole discretion, experimentation with any given test article will cease if safe, controllable operation cannot be maintained.

The tests listed below will be used to determine Performer Test Article performance relative to the metrics listed in Table 3 (Track 1) or Table 4 (Track 2) in Section 1.E, but the T&E team may perform additional testing on components or systems to ascertain performance variation, potentially including, quantum efficiency (QE), photoluminescene, electroluminescence, infrared thermography, and other tests not listed below. Since Phase 1 physical deliverables consist of test articles with POC + COTS components that may not fully represent the system-level performance expected, for the purposes of Phase 1 power system testing, Performers must supply a model that includes equations and assumptions into which measured data from the test articles shall be input to demonstrate that the metrics for Phase 1 will be met. Assumptions and modeling methodology must be explained and will be assessed by the T&E team at specific points throughout the program to assess reasonableness.

Over the course of the program, Test Articles will be subjected to a variety of conditions to assess performance under varied conditions. In Phase 3, likely environmental stressors will be introduced to test articles to assess performance and better understand next development efforts post-SOLSTICE. These experiments are essential to expose the failure modes that would present risks so that teams can refine their technology designs for improved robustness against the target operational environment. Final testing protocols will be outlined in the T&E testing manual and presented at each program phase kickoff. The tests and procedures outlined in the following sections are preliminary to allow Offerors to understand the anticipated scope of the testing; tests and procedures are subject to change.

1.D.1 TRACK 1 TESTING (Space Applications)

PPSs will be assessed through a combination of room temperature and thermal-vacuum (TVAC) chamber (i.e., radiative heat transfer only) testing before and after stress testing as shown in Table1.

TABLE 1: Track 1 (Space) Test & Evaluation Procedures and Schedule

		POC Samples		**Prototype Power Systems**		
		Phase 1		**Phase 2**		**Phase 3**
	T&E Event #:	**1**	**2**	**3**	**4**	**5**
	Perfomer POP Month Due:	7	14	24	31	43
	Minimum Test Articles Delivered:	1	3	1	3	2
#	**TRACK 1 Testing Procedure**					
1	Thermal cycling	N/A	10 cycles	N/A	30 cycles	30 cycles
2	UV irradiation	N/A	10 d	N/A	30 d	30 d
3	Vacuum outgassing of volatile materials	N/A	Plan	Test	Test	Test
4	Electron and proton irradiation	N/A	N/A	Plan	Test	Test
5	Simulated damage events	N/A	N/A	Plan	Test	Test
6	Mechanical stress	N/A	N/A	N/A	Plan	Test*

Plan ≡ plan developed by the Performer to mitigate the impacts of the respective testing planned for a later T&E event, due at the time of test article submission for the specified T&E event

* Performed after all other testing is completed to help inform the next stage of development

Notes on TRACK 1 Testing Procedures:

(1) Thermal cycling will be performed in an accelerated fashion to emulate the temperature extremes expected for power systems in an earth orbit environment for the equivalent period of time specified in the table. Temperatures from 173 K to 373 K are anticipated to be used, but will be finalized in the T&E Manual. A light I-V sweep will be taken at intermediate time intervals (between the exposure start and the timepoint listed in the table) and compared to the initial measurement. Thermal cycling will cease if any of the intermediate timepoints reveals a change in the P_{mp} by more than 50% relative to initial measurement.

(2) Accelerated UV aging of samples will be carried out using UV wavelengths characteristic of the AM0 solar spectrum for the equivalent period of time specified in the table. A light I-V sweep will be taken at intermediate time intervals (between the exposure start and the timepoint listed in the table) and compared to the initial measurement. UV irradiation testing will cease if any of the intermediate timepoints reveals a change in the P_{mp} by more than 50% relative to initial measurement. Phase 1 test articles may contain protective measures for components not intended to be radiated which will not count against the weight metric.

(3) Samples will be exposed to a thermal-vacuum chamber (~77 K and ~10^{-6} torr) over a range of temperatures to ascertain the degree of volatile condensable materials (VCMs) that are

released. An encapsulation plan will need to be developed by Performers and approved by the T&E team within Phase 1 to limit/avoid the amount of VCMs. PPSs will be tested in Phases 2 and 3 at each T&E event prior to additional experiments requiring use of a TVAC chamber.

(4) keV electron/proton irradiation testing with fluence levels consistent with a multi-year mission in GEO using protocols informed from AIAA S-111 (Qualification and Quality Requirements for Space Solar Cells)

(5) Aperture areas will be subjected to a combination of non-destructive and potentially damaging tests (performed last on test articles) designed to simulate single-event threats in a space environment, including debris/micrometeoroid impact damage, high flux irradiation at multiple angles of incidence, and other potential physical threats. Sizes on the order of several square centimeters for the simulated debris or high flux irradiation spot size should be assumed. Power density measurements will be conducted before and after the simulated threat tests.

(6) Preliminary assessment of mechanical stress risks associated with launch and deployment, particularly vibration. A plan to address mechanical stresses associated with vibrational testing will need to be developed and approved by the T&E team within Phase 2. Performance of PSTs before and after vibrational testing in Phase 3 will be assessed.

The following tests will be leveraged throughout the T&E events:

Test 1.1: Power Density. In Phase 1, Performers will provide models and calculations that project power density and specific power at the PPS power levels designed for Phases 2 and 3 using experimentally-derived performance of components (e.g. PV I-V curve, optical efficiency, DC-DC conversion efficiency) fabricated in Phase 1 and reasonable assumptions/extrapolations. In Phases 2 and 3, to determine a PPS's specific power and power density, each of the PPS Test Articles will be weighed and its volume and aperture area will be determined (subtracting-out the weight and volume of the PST in Phases 2 and 3 using an empty PST provided by the Performer). Aperture area will be determined by tracing the perimeter of the outer-most area intended to absorb light using the test article central axis as a reference. Beginning of Life (BOL) specific power and power density will be calculated based upon each test article's median P_{mp} over the initial hold time at 298 K, and its mass or volume. The median result of these tests across all test articles in a T&E event will be compared against target values in Table 3 in Section 1.E. of this BAA, at STP for Phase 1 and the first T&E event of Phase 2, and under TVAC conditions for the remaining T&E events. EOL power density estimations will be extrapolated from BOL and the results of performance testing before and after the stress testing described in the table above using modeling performed by the T&E team. Power density and specific power will be measured under the following conditions:

a. **Standard Temperature and Pressure (STP) testing.** Test articles will be maintained at 298 K under AM0 solar-simulated light for a period of time to measure the stability of the output and variability between test articles. (i.e. any built-in thermal control on the PPS in Phases 2 and 3 will be supplemented via outside temperature control devices to maintain 298 K) The median of the W_{mp} data captured over the hold period will be compared to the minimum power output metric. A light and dark I-V sweep will be captured and key parameters will be extracted (i.e. I_{sc}, V_{oc}, V_{mp}, I_{mp}, P_{mp})

b. **Temperature dependence.** Test Articles will be maintained at specific temperatures between approximately 273 – 310 K until they reach thermal equilibrium. A light and dark I-V sweep will then be captured at that temperature setpoint and key data points will be extracted (i.e. I_{sc}, V_{oc}, V_{mp}, I_{mp}, P_{mp}). The temperature will be adjusted within the aforementioned range at increasing amounts toward the extremes and the experiment will be repeated until the full range has been captured or the test article fails. In this manner, a P_{mp} vs temperature plot will be generated.
c. **TVAC testing.** In Phase 2, T&E Event 4 and Phase 3, T&E Even 5, PPS test articles will be placed in a TVAC chamber (approximately 77 K and 10^{-6} torr) where they will achieve thermal equilibrium and then exposed to AM0 solar-simulated light. The PPS temperature will be monitored continually for a period of time and an I-V characteristic will be captured periodically throughout the test.
d. **Angular Dependence**. Test Articles will be oriented at various angles of incidence (AOI) relative to the simulated solar flux. In Phase 1, if appropriate for the test articles received, test articles will be mounted to a stage that can achieve various AOIs from 0-90 deg across an aperture hemisphere and I-V curves will be captured at 298 K in a manner similar to that described in Test 1.1a. In Phases 2 and 3, PPSs will be mounted to a similar stage to adjust AOIs from 0-90 deg across an aperture hemisphere and I-V curves will be captured at 298 K as well as within a TVAC chamber (approximately 77K and ~10^{-6} torr).

Test 1.2: Surface reflection and IR signature. Assessment of exposed energy conversion area solar-weighted average reflectance at various AOI will be determined. Thermal IR emission will be quantified relative to the background environment at various points in time.

Energy harvesting yield (EHY) simulations

A significant component of the SOLSTICE program revolves around simulation of power system EHY over a given mission lifetime. The T&E team will construct an orbital modeling framework to predict EHY of PPSs with several notional orbital parameters from LEO to GEO. BOL and EOL baseline and Performer-assembled PPS performance will be assessed according to the T&E test manual. Performance of each PPS over a simulated 10-year mission at each orbit will be extrapolated, taking into account degradation observed in performance and durability testing on performer PPSs. Key factors impacting PPS performance such as sun-angle over time, shading, and temperature will be taken into account, where applicable, including Performer strategies to mitigate negative impacts. The EHY predicted by this modeling framework will be compared to a baseline PPS fabricated by the T&E team for the target 10-year mission lifetime. The first mission year energy captured divided by the energy available from sunlight (and/or other sources) will be used for the Metric 1 time-averaged system efficiency calculation. (See Section 1.E Program Metrics)

1.D.2 TRACK 2 TESTING (Terrestrial Surface Applications)

PPSs will be assessed through a combination of room temperature and elevated/reduced environmental temperature testing (approximately 253 – 353 K) before and after stress testing as shown in Table 2.

TABLE 2: Track 2 (Terrestrial) Test & Evaluation Procedures and Schedule

		POC Samples		**Prototype Power Systems**		
		Phase 1		**Phase 2**		**Phase 3**
	T&E Event #:	**1**	**2**	**3**	**4**	**5**
	Performer POP Month Due:	7	14	24	31	43
	Minimum Test Articles Delivered:	1	3	1	3	2
#	**TRACK 2 Testing Procedure**					
1	Thermal cycling	N/A	10 cycles	N/A	30 cycles	30 cycles
2	AM1.5G UV irradiation	N/A	10 d	N/A	30 d	30 d
3	Damp heat test	N/A	N/A	Plan	10 d	30 d
4	Soiling	N/A	N/A	N/A	Test	Test
5	Simulated damage events	N/A	N/A	Plan	Test	Test
6	Mechanical stress (vibration, shock, bending)	N/A	N/A	N/A	Plan	Test*

Plan = plan developed by the Performer to mitigate the impacts of the respective testing planned for a later T&E event, due at the time of test article submission for the specified T&E event

* Performed after all other testing is completed to help inform the next stage of development

Notes on Testing Procedures:

(1) Thermal cycling will be performed in an accelerated fashion to emulate the temperature extremes expected for solar absorbers on the earth for the equivalent period of time specified in the table. Temperatures from 228-358 K are anticipated to be used, but will be finalized in the T&E Manual. A light I-V sweep will be taken at intermediate time intervals (between the exposure start and the timepoint listed in the table) and compared to the initial measurement. Thermal cycling will cease if any of the intermediate timepoints reveals a change in the P_{mp} by more than 50% relative to initial measurement.

(2) Accelerated UV aging of samples will be carried out using UV wavelengths characteristic of the AM1.5G solar spectrum for the equivalent period of time specified in the table. A light I-V sweep will be taken at intermediate time intervals (between the exposure start and the timepoint listed in the table) and compared to the initial measurement. UV irradiation testing will cease if any of the intermediate timepoints reveals a change in the P_{mp} by more than 50% relative to initial measurement. Phase 1 test articles may contain protective measures for components not intended to be radiated which will not count against the weight metric.

(3) 85 deg C/85% RH test consistent with IEC 61215

(4) Simulated soiling and “natural” cleaning (i.e. as could be expected from rain, wind) protocols will be performed on aperture areas and power density measurements will be captured in both soiled and cleaned states to assess the impacts on mission lifetime energy harvesting yield (EHY).

(5) To assess the resilience of the system after potential damage events, a portion of the aperture area (and other potential energy conversion area) will be occluded/disabled in a non-destructive fashion. Sizes on the order of several square centimeters for the simulated disabled area should be assumed. Power density measurements (as described in Test 1.1) will be conducted before and after the simulated impact.

(6) Preliminary mechanical stress testing including vibration, shock, and bending (wind loading), consistent with autonomous deployment and weather conditions expected in earth surface environments, protocols TBD.

The following tests will be leveraged throughout the T&E events:

Test 2.1: **Power Density.** In Phase 1, Performers will provide models and calculations that project power density and specific power at the PPS power levels designed for Phases 2 and 3 using experimentally-derived performance of components (e.g. PV I-V curve, optical efficiency, DC-DC conversion efficiency) fabricated in Phase 1 and reasonable assumptions/extrapolations. In Phases 2 and 3, to determine the PPS’s specific power and power density, each of the PPSs will be weighed and its volume will be determined (subtracting-out the weight and volume of the PST in Phases 2 and 3 using an empty Performer-provided PST). Aperture area will be determined by tracing the perimeter of the outer-most area intended to absorb light using the test article central axis as a reference. BOL specific power and power density will be calculated based upon each test article’s median P_{mp} over the initial hold period at 298 K, and its mass or volume. The median result of these tests across all test articles in a T&E event will be compared against target values in Table 4 in Section 1.E. of this BAA. EOL power density estimations will be extrapolated from modeling performed by the T&E team to capture the impacts of environmental stressors as determined by stress testing discussed above. Power density and specific power will be measured under the following conditions:

a. **Standard Temperature and Pressure (STP) testing.** Test articles will be maintained at 298 K under AM1.5G solar-simulated light for a period of time to measure the stability of the output and variability between test articles. (I.e. any built-in thermal control on the PPS in Phases 2 and 3 will be supplemented via outside temperature control devices to maintain 298 K) The median of the W_{mp} data captured over the hold period will be compared to the minimum power output metric. A light and dark I-V sweep will be captured and key parameters will be extracted (i.e. I_{sc}, V_{oc}, V_{mp}, I_{mp}, P_{mp})

b. **Variable irradiance testing.** Test articles will be maintained at 298 K under direct normal AM1.5G solar-simulated light at varying irradiance levels between 0-1000 W/m^2. A light I-V sweep will be captured to generate a P_{mp} vs irradiance plot.

c. **Temperature dependence.** Test articles will be maintained at specific temperatures between approximately 273-310 K (Phase 1) and 228-358 K (Phases 2 and 3) until they reach thermal equilibrium under direct normal AM1.5G solar-simulated light. A light and dark I-V sweep will then be captured at that temperature setpoint and the key parameters will be extracted (i.e. I_{sc}, V_{oc}, V_{mp}, I_{mp}, P_{mp}). The temperature will be adjusted within the aforementioned range at increasing amounts toward the extremes and the experiment will be repeated until the full range has been captured or the test article fails. In this manner, a P_{mp} vs temperature plot will be generated.

d. **Angular Dependence**. Test Articles will be oriented at various angles of incidence (AOI) relative to the simulated solar flux. In Phase 1, if appropriate, test articles will be mounted to a stage that can achieve various AOIs from 0-90 deg across an aperture hemisphere and I-V curves will be captured at 298 K in a manner similar to that described for the STP testing. In Phase 2, PPSs will be mounted to a similar stage to adjust AOIs from 0-90 deg across an aperture hemisphere and I-V curves will be captured at 298 K as well as at various surrounding temperatures between 228-358 K.

Test 2.2: Surface reflection and IR signature. Assessment of exposed energy conversion area solar-weighted average reflectance at various AOI will be determined. Thermal IR emission will be quantified relative to the background environment at various points in time.

Energy harvesting yield (EHY) simulations

A significant component of the SOLSTICE program revolves around simulation of power system EHY over a given mission lifetime. The T&E team will construct a modeling framework to predict EHY of PPSs with several notional land or water-based environments in mind. Target environments used for extrapolating performance will be specified at Program Kickoff, but can be assumed to encompass the range of possible climates present across the United States. BOL and EOL baseline and Performer-assembled PPS performance will be assessed according to the test manual. Performance of each PPS over a simulated 3-year mission in each environment will be extrapolated, taking into account degradation observed in performance and durability testing on performer PPSs. Key factors impacting PPS performance such as temperature, sun-angle over time, latitude, weather, shading from soiling, and other impacts will be taken into account, where applicable, including Performer strategies to mitigate negative impacts. The EHY predicted by this modeling framework will be compared to a baseline PPS fabricated by the T&E team for the target 3-year mission lifetime. The first mission year energy captured divided by the energy available from sunlight (and/or other sources) will be used for the Metric 1 time-averaged system efficiency calculation. (See Section 1.E Program Metrics)

1.E. Program Metrics

IARPA research programs include rigorous evaluations using carefully designed technical performance metrics. Performance against the metrics is used to inform decision-making in IARPA research programs; for example, the exercise of options to continue performance under research contracts will be based on achievement of program metrics. IARPA has defined program metrics to evaluate effectiveness of the proposed solutions in achieving the stated program goal and objectives, and to determine whether satisfactory progress is being made to warrant continued funding of the Performers. The metrics described in this BAA are shared with the intent to bound the scope of the effort, while affording Offerors maximum flexibility, creativity, and innovation in proposing solutions to the stated problem. Proposals with a plan to exceed the defined metrics in one or more categories are desirable, provided that all of the other metrics are met, and that the proposals provide clear justification as to why the proposed approach will be able to meet or exceed the enhanced metric(s). Program metrics may be refined during the various phases of the SOLSTICE program; if metrics change, revised metrics will be communicated to Performers as quickly as possible.

Track 1: Space-based Energy Conversion Systems

Metrics for Track 1 are shown in Table 3. Offerors may consider an earth-orbiting satellite in geostationary orbit as a representative spacecraft, but proposed power systems should be generally applicable to earth-orbiting spacecraft since the metrics represent aggressive performance objectives applicable to multiple mission-critical power requirements. Unless otherwise noted, metrics represent the median performance (measured or modeled) across all test articles submitted for a particular T&E event. Areal power density targets are listed for Beginning of Life (BOL) and End of Life (EOL) at the ten-year timepoint to drive Offerors to propose solutions that will be durable. EHY and EOL values will be modeled from BOL, experimentally-derived degradation factors, and other extrapolations drawn from Test Article performance.

TABLE 3: Technical Metrics for Track 1.
Space-based Energy Conversion Systems

#	Performance Parameter	Phase 1: Modeled POC System[3]	Phase 2: Prototype Demonstration	Phase 3: Scalability & Durability Assessment
1	BOL time-weighted system-level energy efficiency (%)	≥ 30	≥ 30	≥ 35
2	BOL and EOL system aperture area power density (W_{mp}/m^2)	BOL: ≥ 478	BOL: ≥ 478 EOL: ≥ 406	BOL: ≥ 550 EOL: ≥ 495
3	BOL system volumetric power density (kW_{mp}/m^3)	≥ 20	≥ 30	≥ 30
4	Demonstration peak power output (W_{mp})	N/A	≥ 7	≥ 30
5	BOL system specific power (W_{mp}/kg)	≥ 80	≥ 100	
6	Loss of P_{mp} following damage event (%)	N/A	< 20	

Detailed Metrics Description:

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[3] Target system performance parameters for Phase 1 will be calculated from measured component parameters and modeling/simulation results. See the explanation provided in Section 1.D Testing and Evaluation.

(1) Time-weighted system-level efficiency of capture and conversion of incident energy into direct current (DC) output, following any energy or power conversions over the first year of operation. Calculation uses available solar spectrum and/or other available energy for an assumed orbit in GEO, calculated hourly, factoring-in an assumed pointing tolerance specified by the Performer that can be accomplished with a commercially-available tracker (if needed). Calculation uses the EHY of the system modeled for the first year of operation divided by the available sunlight energy over the same period of time. (See "Energy harvesting yield simulation" in Section 1.D Test and Evaluation above) As indicated above, Phase 1 metrics are determined from STP testing of components and models extrapolating PPS performance. Phase 2 and 3 efficiencies are determined from time-averaged measurements performed in a TVAC chamber for the range of conditions (e.g. temperature, AOI) expected from the PPS on orbit.

(2) Beginning of Life (BOL) and End of Life (EOL) two-terminal system power output at maximum power point following any power conversion/optimization needed to reach target voltage/current for simulated loads divided by exposed area required for sunlight or other energy collection/conversion; measured under direct normal 1366 W/m^2 Air Mass 0 (AM0) standard solar-simulated light, following a pre-determined stabilization period (e.g. 1h); For Phase 1, measured at 298 K standard temperature and pressure (STP) surrounding environment. For Phases 2 and 3, measured within a thermal-vacuum (TVAC) chamber. No effort will be made to maintain test article at STP. Performers will be required to manage heat loads to maximize performance in a TVAC environment (i.e. only radiative heat transfer is available). Aperture area will be determined by tracing the perimeter of the outer-most area intended to absorb light using the test article central axis as a reference. EOL is modeled using the BOL measurement and projected performance changes indicated from degradation data derived from testing indicated in Section 1.D.1.

(3) Stowed volume inclusive of all active and passive components from light collection to two-terminal output; measured at BOL.

(4) Minimum steady-state output of test article at max power point (prior to any energy storage) under illumination with AM0 1366 W/m^2 solar-simulated light at STP.

(5) BOL maximum power point following a pre-determined stabilization period (e.g. 1 hr) divided by total mass of Performer-integrated components on/in the PST (i.e. weight of the PST will not be counted)

(6) Several tests will be conducted to simulate potential damage mechanisms at locations across the test article aperture area (chosen by the T&E team), including, a) high flux irradiation performed at specific angles of incidence, b) a several cm^2 diameter debris impact localized to a similarly-sized segment of the aperture, and c) a several cm^2 ESD damage site. Comparison will be made between pre and post testing P_{mp} in a TVAC chamber.

Track 2: Terrestrial Surface-based Energy Conversion Systems

Metrics for Track 2 are shown in Table 4. While Track 2 is aimed at powering remotely-deployed unattended systems in terrestrial surface environments, the metrics have not been set with any particular electronic devices or deployment environment in mind. Rather, the metrics represent aggressive performance objectives, achievement of which will extend the performance of multiple systems operating in a range of environments. In Phase 3 of SOLSTICE, durability of systems against potential environmental stressors will be assessed. Target environments used for extrapolating performance will be specified at Program Kickoff, but can be assumed to encompass the range of possible climates present across the United States. Unless otherwise noted, metrics represent the median performance (measured or modeled) across all test articles submitted for a particular T&E event. Areal power density targets are listed for Beginning of Life (BOL) and End of Life (EOL) at the 3-year timepoint to drive Offerors to propose solutions that will be durable. EHY and EOL values will be modeled from BOL, experimentally-derived degradation factors, and other extrapolations drawn from Test Article Performance.

TABLE 4: Technical Metrics for Track 2. Terrestrial Surface Energy Conversion Systems.

#	Performance Parameter	Phase 1: Modeled POC System[4]	Phase 2: Prototype Demonstration	Phase 3: Scalability and Durability Assessment
1	BOL Time-weighted System Energy Efficiency (%)	≥ 30	≥ 30	≥ 35
2	BOL and EOL system aperture area power density (W_{mp}/m^2)	BOL: ≥ 370	BOL: ≥ 370 EOL: ≥ 315	BOL: ≥ 390 EOL: ≥ 351
3	BOL system volumetric power density (kW_{mp}/m^3)	≥ 20	≥ 30	≥ 30
4	Demonstration peak power output (W_{mp})	N/A	≥ 5	≥ 20
5	BOL System specific power (W_{mp}/kg)	≥ 60	≥ 80	

Detailed Metric Description

(1) Time-weighted system-level efficiency of capture and conversion of incident energy into direct current (DC) output, following any energy or power conversions over the first year of operation. Calculation uses available solar spectrum and/or other available energy for a series of assumed locations on earth (determined by the T&E team where spectrum data is available), calculated hourly, for a stationary device with aperture area pointing at fixed tilt as specified by the Performer. Calculation uses the EHY of the system modeled for the first year of operation divided by the available sunlight energy over the same period of

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[4] Target system performance parameters for Phase 1 will be calculated from measured component parameters and modeling/simulation results for the target environment. See the explanation provided in Section 1.D Testing and Evaluation.

time. (See "Energy harvesting yield simulation" in Section 1.D Test and Evaluation above) As indicated above, Phase 1 metrics are determined from STP testing of components and models extrapolating PPS performance. Phase 2 and 3 efficiencies are determined from time-averaged measurements performed on PPSs for the range of conditions (e.g. temperature, irradiance level, AOI) expected in the respective locations.

(2) Beginning of Life (BOL) and End of Life (EOL) two-terminal system power output at maximum power point following any power conversion/optimization needed to reach target voltage/current for simulated loads divided by exposed area required for sunlight or other energy collection/conversion; measured at 298 K Standard Temperature and Pressure (STP) surrounding environment under direct normal 1000 W/m^2 Air Mass 1.5G (AM1.5G) standard solar-simulated light following a pre-determined stabilization period (e.g. 1h). NOTE: During Phase 2 and 3 testing, no effort will be made to maintain test article at STP. Performers will be required to manage heat loads to maximize performance. Aperture area will be determined by tracing the perimeter of the outer-most area intended to absorb light using the test article central axis as a reference. EOL is modeled using the BOL measurement and projected performance changes indicated from degradation data derived from testing indicated in Section 1.D.2. PSTs must achieve the stated metrics in at least one of the target environments modeled.

(3) Stowed volume inclusive of all active and passive components from light collection to two-terminal output; measured at BOL.

(4) Minimum output of test article upon illumination with AM1.5G 1000 W/m^2 solar-simulated light at STP.

(5) BOL maximum power point following a pre-determined stabilization time (e.g. 1 hr) divided by total mass of Performer-integrated components on/in the PST (i.e. weight of the PST will not be counted)

1.F. Program Schedule and Deliverables

This section describes the program schedule, including Waypoints, Deliverables and Milestones.

1.F.1. Waypoints

Waypoints are Government- and Offeror-defined, task-driven intermediate steps toward achieving the program objectives. Waypoints are measurable accomplishments reflected in the work plan and depicted on the schedule. They are typically traceable to the metrics. Waypoints provide additional insight into the development of the key aspects of the proposed research beyond the measurement of deliverable performance metrics. They assist the program management team to provide guidance and assistance to Performer teams and will be reviewed during Site Visits and Technical Review Meetings (see Section 1.F.2 below). The waypoints will also be used by the Program Manager (PM) to assess the need for any course correction during the program. Program waypoints may be refined during the various Phases of the program; if waypoints and milestones change, these will be communicated to Performers as quickly as possible.

Offeror's proposed technical and programmatic waypoints shall be included in the Offeror's proposal. For each proposed waypoint, the proposal shall describe the waypoint, its relationship to program tasks(s) and metrics, criteria for successful achievement of the waypoint, and the date by which the waypoint shall have been achieved. It is preferred that this waypoint information be conveyed in tabular format.

1.F.2. Deliverables

A description of the program deliverables follows.

Technical Management Plan (TMP)

Performers shall provide a plan for successful execution of their proposed project, including timetables for delivery of key components, integrations, and other technical milestones by all team members involved. The TMP will be discussed and agreed-upon with the Program Manager before the start of each Program Phase. Review and update of the TMP will take place generally at each Technical Review Meeting with changes agreed-upon with the Program Manager.

Power System Test Article Deliverables

Performers shall provide power solution test article deliverables as described in Section 1.D. Testing & Evaluation (T&E) and shown in the program schedule in Table 5 in Section 1.F.3 Program Milestone, Deliverables and Testing Timeline (below).

Component and Power System Model Deliverables

Performers shall provide design documents and modeling and/or other calculations to demonstrate that their component solutions and system level approach can be expected to meet the program metrics for the Phase in which they are due. Models shall also support the Performer's ability to meet Phase 3 metrics by the end of the program.

Technical Reporting

Performers shall provide monthly technical reports no later than 10 days after the first of each month. The technical reports shall include data presented at monthly technical review meetings and will serve as background material for discussion at subsequent meetings. Both the results presented at technical review meetings and technical reports will serve as an official record of progress. Technical reports shall include the results of internal performance tests as follows. Performers are expected to evaluate their components and power systems continually throughout the program to measure progress toward achieving program metrics. Internal performance testing shall be a subset of the test protocols described in Section 1.D. The results of internal performance testing shall be included in the Monthly Technical Reports, as internal performance testing is completed, no less frequently than every six months throughout program performance. The first Monthly Technical Report shall contain a description of the Performer's testing methodology for internal performance testing. The Performer and the PM shall agree on the Performer's testing methodology not later than the 3rd month after program kickoff, with the first internal testing to be completed not later than the 6th month of the program.

Kickoff and Program Wide Review Meetings

Kickoff and program wide review meetings shall be held at a location to be determined by the PM, typically in the Washington, D.C. metropolitan area, where Performers shall share non-proprietary information and/or updates with the other Performers. All active Performer teams at the time of Program-wide meetings will be expected to attend unless otherwise directed by the Program Manager. Typically, program-wide review meetings, also known as Principal Investigator (PI) Meetings, will also include breakout sessions for each team to meet individually with the PM, the program management team and the T&E team. At these breakout sessions, any results the Performers assert are proprietary shall be discussed. Performers shall plan to send no more than 2-3 key technical personal to the program wide review meetings, unless otherwise agreed with the PM. Unless otherwise specified in the program schedule or by the PM, kickoff and program wide review meetings are in addition to the monthly technical review meetings.

Technical Review Meetings

Performers shall support monthly technical review meetings in person at the Performer’s site (see Site Visits below) or remotely (e.g., by means of telephone, Skype, WebEx, video conference or otherwise, at the discretion of the PM). During these monthly technical review meetings, Performers will present their results, describe their progress toward waypoints and achievement of performance metrics, and identify any issues that may affect their ability to meet metrics, milestones, or overall program objectives.

Technical Exchange Meetings/Workshops

Throughout the Program, the PM may call meetings specifically for discussion of topics common to several or all Performers (e.g. technical challenges, market updates, technology transfer considerations). These meetings may occur virtually or in-person at TBD locations. Performers will be expected to attend and engage with other attendees and present on their results if requested by the PM. These meetings are anticipated to take place no more frequently than once per year.

Site Visits

Semi-annual site visits will occur throughout the life of the SOLSICE program. The SOLSTICE program management team and invited representatives of Government agencies will visit each Performer (and/or subcontractors) at their work site to conduct an in-depth review of progress toward program objectives and to meet with team members. Performers shall host these site visits at the sites where research for the SOLSTICE program is being performed. During site visits, Performers will show their physical capabilities, and introduce the researchers working on the program to the program management team and invited Government representatives. The site visit shall be concurrent with the technical review meeting to be held in the same month. Reports on technical progress, details of successes and issues, contributions to the program goals, and technology demonstrations will be expected at site visits. Performers shall participate and provide final meeting documents, to include captured action items, within 15 calendar days following the meeting. Draft materials, for any presentations, are due 5 workdays prior to the meeting. IARPA reserves the right to conduct additional site visits on an as-needed basis.

Financial Reporting

Performers shall provide monthly status reports (MSRs) not later than ten days after the first of each month. The MSRs shall summarize budget and spending and identify any financial issues that may affect the program or put achievement of program objectives at risk.

1.F.3. Program Milestone, Deliverables and Testing Timeline

The SOLSTICE program will follow the timeline in Table 5. Table 5 shows milestones, deliverables dates, testing dates, and dates for program review meetings, including site visits.

TABLE 5: Program Milestone, Deliverables and Testing Schedule.

Event	Months after Kick-off			Deliverables
	Phase I	Phase II	Phase III	
Kickoff Meeting (Beginning of each Phase)	1	19	37	Read-ahead package due from Performers to the Government 7 days before meeting. If required by the PM, updates after the meeting are due 15 days after the meeting date.
Technical Management Plan (TMP) Deliverables	1	19	37	Finalized schedule and intermediate technical milestones for internal team agreed upon with Program Manager.
Program Wide Review Meeting	12	27	40	Read-ahead package due from Performers to the Government 7 days before meeting. If required by the PM, updates after the meeting are due 15 days the meeting date.
Technical Review Meetings	Monthly	Monthly	Monthly	Read-ahead package due from Performer to the Government 2 days before meeting. If required by the PM, updates after the meeting are due 15 days after the meeting date.
Site Visits	3, 8, 15	22, 28, 34	42	Site visits (to be held concurrently with Technical Review Meetings)
Component Proof of Concept Deliverables	7, 14	-	-	POC components delivered by Performer for T&E. Deliverables shall be received at the T&E site specified by the Government no later than the final day of the listed month.
Power System Test Article Deliverables	-	24, 31	43	Power system delivered by Performer for T&E. Deliverable shall be received at the T&E site specified by the

Event	Months after Kick-off			Deliverables
	Phase I	Phase II	Phase III	
				Government no later than the final day of the listed month.
Power System Model & Design Deliverables	4, 10, 17	27, 34	41	Power system and component models + system design delivered by Performer for T&E. Deliverable shall be received at the T&E site by the Government no later than the final day of the listed month.
Power system cost model deliverable	N/A	33	46	Performers must deliver a model that details assumptions and calculations to arrive upon an estimated direct hardware costs incurrent year USD per Watt DC output. Modeled direct hardware costs are inclusive of all components required for light absorption to two-terminal power delivery to loads, assuming 200 kW/y power system production volume.
Independent T&E	8-9, 15-16	25-27, 32-34	44-46	Upon receipt of the Performer Test Article Deliverables, T&E will be conducted. Performers may expect test results within two months of test article submission, but no later than the last day of the listed range of months.
Financial and Technical Reports	Monthly	Monthly	Monthly	Monthly financial and technical reports are due by the 10th day of the following month.
End of Phase	18	36	48	Phase Period of Performance Ends

1.F.4. Meeting and Travel Requirements

Performers are expected to assume responsibility for administration of their projects and to comply with contractual and program requirements for reporting, delivery of power solutions for testing, and attendance at program meetings, either at their research facility or at another location to be determined by the PM. Table 5 describes expectations for meetings and travel for the SOLSTICE program. Section 1.F.2. Deliverables describes locations where meetings are to be held as well as the contemplated frequency and locations of such meetings. In addition to ensuring that all required deliverables are made on time, each Performer will be required to be available to the T&E team for questions and troubleshooting during monthly status meetings.

1.F.5. Place of Performance

Performance will be conducted at the Performers' (including subcontractors') sites.

1.F.6. Period of Performance

The SOLSTICE Program is envisioned as a 48-month effort that is intended to begin January 1, 2025. Phase 1 will last 18 months; Phase 2 will last 18 months; and Phase 3 will last 12 months.