

**Disruption Opportunity
DARPA-PA-25-07-03**

Cathode Advancements in Science and Technology for Oxygen Resistance (CASTOR)

I. Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) is issuing a Disruption Opportunity (DO), inviting submissions of innovative basic or applied research for efficient, high-performance, long-lived oxygen-compatible cathodes for use in air-breathing very low earth orbit (VLEO) electric propulsion (EP) systems. This DO is issued under the Program Announcement for Disruptioneering, DARPA-PA-25-07. All awards will be made in the form of an Other Transaction (OT) for Prototype project. The total award value for the combined Phase 1 base (Feasibility Study) and Phase 2 option (Proof of Concept) is limited to \$900,000 (see Section I.C for information more information on phase structure). This total award value includes Government funding and performer cost share if required or proposed.

To view the DARPA Program Announcement (PA) for Disruptioneering, visit SAM.gov under solicitation number DARPA-PA-25-07:

<https://sam.gov/opp/bae5fa32f4ee4cdb9a070a14309b2c66/view>.

A. Introduction

Today's spacecraft electric propulsion systems, such as Hall thrusters, use thermionic cathodes to ignite, sustain, and neutralize an ion beam. These hot cathodes operate on noble gases with delicate chemistry that poison (fail) rapidly in trace amounts of air or water. CASTOR targets a compact, long-lived, efficient electron source for spacecraft EP systems operating on oxygenic species, capable of supplying from one to tens of amperes electrical current. The goal is a cathode that can operate using purely air or water as the main working fluid while matching today's noble gas performance. CASTOR focuses on air and water as ubiquitous but extremely challenging oxygenic species, where success will extend the operating envelope of EP systems to the broadest possible range of alternative fuels.

B. Objective/Technical Scope

The goal of CASTOR is to develop new cathodes capable of supporting EP thrusters operating on air or water for 1,000 hours or more while matching the performance of today's cathodes operating on noble gases. Today's spacecraft EP systems provide excellent fuel efficiency by accelerating positively-charged ions to exhaust velocities an order of magnitude higher than chemical rockets, but most thrusters also require electron emitting cathodes to neutralize the departing ions and prevent spacecraft charging. Typical systems such as Hall thrusters use hot thermionic cathodes, which are notoriously incompatible with oxygen because they rely on a thermionic emitting material with an exceptionally low barrier energy to releasing electrons into vacuum. Electronegative oxygen atoms and molecules bind to the emitting surfaces, "poisoning" them and reducing or entirely suppressing further emission current from the thermionic cathode. CASTOR's cathodes target operation in oxygenic environments with capacity, efficiency, and lifetime comparable to a xenon-fed thermionic cathode.

The goals of the CASTOR program are ambitious and may require leveraging multiple electron emission mechanisms in addition to or instead of thermionic emission (TE) within a single cathode. Cathodes using field emission (FE), photoemission (PE), secondary electron emission (SEE), and/or gas phase ionization such as in radio frequency (RF) plasma cathodes have all

been developed in EP and non-propulsion fields (e.g., plasma cutting torches, neon lights), but never at the performance or lifetime needed for electric propulsion.

To achieve the program metrics, we seek creative approaches leveraging a wide variety of these emission mechanisms, either individually or in combination, such as: thermal-field emitters using low work function coatings on sharp tips, field emitters using a plasma sheath as a conformal gate, microhollow cathode arrays leveraging microfabrication and oxide layer tunneling, refractory oxides operated at semiconducting temperatures, interfacial methods applying band bending or negative electron affinity, and many more.

C. Structure

CASTOR is a two-phase, 21-month program. Phase 1 is a 9-month concept exploration with benchtop testing in ambient gas and plasma conditions representative of a spacecraft electric propulsion system operating on oxygenic fuels. Phase 2 is a 12-month design refinement culminating in delivering a cathode test article to the Government. Performers must perform the majority of cathode testing during both Phases in their own facilities. The program will also provide the option during pre-defined periods in each Phase to leverage supplemental test facilities at the U.S. Naval Research Laboratory, in partnership with the Government independent validation and verification (IV&V) team.

Prior to commencing testing in Phase 1, the performer will present a detailed test plan and schedule. This test plan will include vacuum, mechanical, electrical, sensor, and data acquisition interfaces, including a description of the test's thruster representative environment (TRE): a background neutral gas pressure and plasma density typical of an EP thruster cathode environment. Testing will include argon and either air or water (or both). The pressure may vary across a rough vacuum range of approximately 10^{-4} to 1 Torr, i.e., it should be neither at high vacuum nor atmospheric pressure. During Phase 1, the performer will iteratively test designs to complete lifetime performance tests (LPT) in a TRE of increasing duration (1-hour, 10-hour, and 100-hour) leading up to a final Phase 1 review.

In Phase 2, selected performers will refine their design, present, and execute a test plan for more aggressive efficiency metrics over a longer lifetime with both air and water oxygenic species. The TRE must include a background neutral gas pressure and a representative plasma density. Phase 2 will include interim 300-hour and final 1,000-hour LPTs in the performer TRE. Phase 2 will culminate with the delivery of a cathode prototype to the Government.

A Government independent verification and validation (IV&V) team will assist with CASTOR. Performers will have access to the IV&V team for guidance and collaboration during key milestones and testing phases. A Technical Interchange Meeting (TIM) will be held in each phase, serving as a collaborative forum for all performers to present their technical approaches and progress. These meetings will include the IV&V team as well as invited transition stakeholders to discuss technology transition pathways and potential applications.

Performers may elect to utilize the Naval Research Laboratory (NRL) as a Government test facility during Phase 1 and Phase 2. Test support will be offered by the Government IV&V team during fixed test windows for several weeks near the end of each phase, with specific dates to be determined at program kickoff. Performers may use the NRL facility for up to two days during Phase 1 and up to one week during Phase 2. Test opportunities within these windows will be allocated on a first-come, first-served basis, contingent on a successfully scheduled Test Readiness Review (TRR) conducted in conjunction with NRL at least four weeks prior to the

first test date. In the proposal, performers must specify whether the NRL facility is desired and describe their cathode hardware configuration planned for this testing. NRL has several well-equipped vacuum chambers from 0.5 - 2.5 m in diameter and multiple plasma sources available for TREs. Performers working toward the Phase 1 goal of ampere-level emission may prefer to emit into a cold, dense inductively coupled plasma as their TRE, while performers capable of sufficient amperage may take advantage of Hall thrusters ranging from sub-ampere to tens of amperes in discharge current.

Proposals submitted in response to this DO must be unclassified and must address two independent and sequential project phases: a Phase 1 Feasibility Study (base) and a Phase 2 Proof of Concept (option). The periods of performance for these phases are 9 months for the Phase 1 base effort and 12 months for the Phase 2 option effort. Combined Phase 1 base and Phase 2 option efforts for this DO should not exceed 21 months. The Phase 1 (base) award value is limited to \$350,000. The Phase 2 (option) award value is limited to \$550,000. Both Phase 1 and Phase 2 award value limits include performer cost share, if required, or if proposed. The total award value for the combined Phase 1 and Phase 2 is limited to \$900,000. This total award value includes Government subs funding and performer cost share, if required or if proposed.

D. Detailed Technical Description

CASTOR performers will iterate on prototype devices tested in gas and plasma environments on at least one oxygenic species of either air (~80% N₂ / 20% O₂) or water (H₂O). Table 1 shows program metrics for cathode performance on an oxygenic species, which should be met at the end of the LPT conditions listed in Table 2. Test duration for the LPT will be based on accumulated time on a single device, possibly including interruptions as needed for facility maintenance or test article inspection.

Table 1. CASTOR Metrics

Metric	Phase 1	Phase 2
Power Efficiency	< 50 W/A	< 20 W/A
Mass Efficiency	< 10 sccm/A	< 5 sccm/A

Table 2. CASTOR Test Conditions

Test Condition	Phase 1	Phase 2
Current	1 A	30 A
Duration	100 hrs.	1000 hrs.

Proposals should do the following (as applicable to the proposer's concept):

- Describe the core electron emission mechanism(s) the cathode employs and provide data or calculations to support why this mechanism works in an oxygenic environment.
 - If a combination of mechanisms is proposed, attempt to quantify the effect of each mechanism and explain why the mechanisms work in concert.
- Provide the state-of-the-art performance for each mechanism proposed including any references for both oxygen survivability and efficiency, if available.
- Describe the theoretical limits of your proposed solution and why.

- Describe what is novel and transformational about your proposed solution. The proposal should highlight and focus on the new insights enabling transformational cathode performance. Below are particularly important features to explicitly call out for each mechanism a cathode uses:
 - TE: reason for material's expected oxygen compatibility, fabrication method, expected operating temperature, lifetime limits due to mass loss, and efficiency effects of radiated thermal power
 - RF: expected coil design, plan to counter the inherent efficiency penalties of gas phase molecular ionization, ion collector design, assumed internal plasma density, expected physical size of cathode
 - FE: fabrication methods and maturity, data supporting lifetime estimates, existing data or planned mitigation strategies to address tip dulling from ion impact, and scaling path to manufacture arrays capable of ampere-level currents
 - SEE and PE: expected electron yields, sizing required to achieve the ampere capacities required, conductivity of surface, effect of sourcing high currents through the system, and survivability of surface under ion bombardment
- Describe the core expertise area(s) needed to be successful and the team's capabilities in each area.
- Indicate if use of NRL test facility in Phase 1 or 2 is desired.
 - Note: NRL testing is provided in addition to, not in place of, performer testing.
- Describe plans for testing the proposed cathode, including:
 - Notional cathode design
 - Vacuum test capabilities
 - Expected TRE, including neutral background pressure and plasma density
 - Sensors and measurements required to calculate the metrics in Table 1, including diagram of electrical grounding, biasing, and measurement locations. Specify diode or triode testing.

Proposals that fail to provide evidence, quantitative projections, first order calculations, or theoretical estimations of how the proposed effort can meet or approach the metrics may be deemed non-conforming and removed from consideration. Within the allotted page limit, prioritize reasoned arguments, evidence, and calculations to justify claims. Minimize marketing language and repeating the language from this solicitation.

Proposers should note that meeting the Phase 1 metrics does not guarantee a Phase 2 award. Likewise, if a performer fails to meet the Phase 1 metrics but has a highly innovative, and potentially disruptive approach, DARPA may decide to continue those efforts into Phase 2, subject to the availability of funds.

E. Schedule/Milestones

Proposers must address the following fixed payable milestones in their proposals. Proposers must complete the "Schedule of Milestones and Payments" tab of the Streamlined Cost Buildup Workbook provided with this DO to fulfill the requirements under Volume 2, Price Volume. If selected for award negotiation, the fixed payable milestones provided will be directly incorporated into Attachment 3 of the Other Transactions (OT) agreement ("Schedule of Milestones and Payments"). Proposers must use the Task Description Document template

provided with the Program Announcement DARPA-PA-25-07, which will be Attachment 1 of the OT agreement.

Phase 1 fixed milestones for this program must include, at a minimum, the following:

- Month 1: Kickoff
 - Attend a virtual Phase 1 kick-off meeting and present initial concept from the proposal and path for development.
 - Note: The initial kickoff will be held jointly, and all teams' presentations will be attended by all performers.
 - All positions identified in the proposal are assigned to personnel, and names are provided to the Government.
- Month 2: Conceptual design review (CoDR)
 - CoDR presentation to Government team to include:
 - Detailed cathode test article design
 - Experimental setup including instrumentation and TRE
 - Planned test matrix and schedule
 - Planned hardware development and endpoint over Phase 1
 - All proposed personnel must be working on the project at the planned level of effort.
- Month 3: Quarterly Review 1
 - Present at review meeting to include:
 - Baseline beginning-of-life (BOL) performance in both argon and oxygenic environments
 - Results and analysis from LPT1, ≥ 1 hr., including current and voltage over time and evaluation against Phase 1 metrics
 - Plans for LPT2, ≥ 10 hrs
- Month 6: Quarterly Review 2
 - Present at review meeting to include:
 - Updated BOL performance in both argon and oxygenic environments
 - Results and analysis from LPT2, including current and voltage over time and evaluation against Phase 1 metrics
 - Plans for LPT3, ≥ 100 hrs
 - Provide Government IV&V team raw LPT test data and analysis scripts for independent assessment.
- Month 7: (If utilizing Government test facility)
 - Test cathode at NRL using Government-provided TRE, 2 days' duration.
 - Requires TRR 4 weeks prior
- Month 8: Final Review
 - Present an end-of-phase brief, held virtually or at performer's site, detailing:
 - Updated BOL performance in both argon and oxygenic environments

- Results and analysis from LPT3, including current and voltage over time and evaluation against Phase 1 metrics
 - Lessons learned in Phase 1 and intended path for Phase 2
- Provide Government IV&V team raw LPT test data and updated analysis scripts for independent assessment.
- Document and present the final Phase 1 cathode design, its performance against program metrics, and potential paths to improvement in Phase 2.
- End of Month 8:
 - Present at Technical Interchange Meeting
- End of Phase 1 Period of Performance:
 - Deliver a final Phase 1 report and presentation materials documenting the information covered during the end-of-phase brief.

Phase 2 fixed milestones for this program must include, at a minimum, the following:

- Month 10: Kickoff
 - Attend and present at virtual Phase 2 Kickoff.
 - Document and present design updates since Phase 1 final design review.
 - Present test plan and schedule for Phase 2.
- Month 13: Quarterly Review 1
 - Present initial Phase 2 results.
 - Provide Government IV&V team raw test data and analysis scripts for independent assessment
 - Present plans for LPT4, ≥ 300 hrs.
- Month 16: Quarterly Review 2
 - Present refined Phase 2 results, hardware design status updates, and status of cathode performance against Phase 2 metrics.
 - Report results of LPT4.
- Month 17: (If utilizing Government test facility)
 - Conduct TRR for LPT5 ≥ 1000 hrs. at performer facility
 - Provide raw test data and analysis scripts from best endurance trial to date.
- Month 18: TRR
 - Conduct TRR for LPT6 ≥ 1000 hrs. at performer facility.
 - Provide raw test data and analysis scripts from best endurance trial to date.
- Month 20: Present an end-of-phase brief (held virtually or at performer's site) detailing:
 - Final design configuration of the cathode
 - Test results from all test activities
 - Performance against program metrics
 - Predicted lifespan of the cathode and predicted performance changes throughout its lifespan
 - Recommendations for future design improvements and areas for research

- End of Month 20:
 - Present at Technical Interchange Meeting
- Month 21:
 - Deliver prototype of final cathode design to Government.
 - Deliver a final report and presentation materials documenting information covered during the end-of-phase brief.

For planning and budgetary purposes, proposers should assume a program start date of June 29, 2026. Schedules will be synchronized across performers, as required, and monitored/revised as necessary throughout the program's period of performance.

All proposals must include the following meetings and travel in the proposed schedule and costs:

- Half-day virtual kickoff in both Phase 1 and 2
- To foster collaboration between teams and disseminate program developments, quarterly virtual Principal Investigator (PI) meeting
- Regular teleconference meetings with the Government team for progress reporting and problem identification and mitigation. Proposers should also anticipate at least one site visit per phase by the DARPA Program Manager, during which they will have the opportunity to demonstrate progress towards agreed-upon milestones.
- Two one-day technical interchange meetings; one in Phase 1 and one in Phase 2. For budgeting purposes, the anticipated location is Washington, D.C.
- If requesting Government IV&V for testing, proposers should anticipate travel for a 2-day test window in Phase 1 and a 1-week window in Phase 2. For budgeting purposes, the anticipated location for testing is Washington, D.C.
- Note: Travel costs to support conferences and publication costs should not be included.

F. Deliverables

Performers will be expected to provide, at a minimum, the following deliverables:

- Negotiated deliverables specific to the objectives of the individual efforts. These may include registered reports, experimental protocols, publications, intermediate and final versions of software libraries, code, and APIs, including documentation and user manuals, and/or a comprehensive assemblage of design documents, models, modeling data and results, and model validation data.

II. Award Information

Selected proposals that are successfully negotiated will result in the award of an OT for Prototype project. See Section 4 of DARPA-PA-25-07 for information on awards that may result from proposals submitted in response to this announcement.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-25-07 prior to submitting a proposal. DARPA has provided the model OT to expedite the negotiation and award process and ensure DARPA achieves the goal of Disruptioneering, which is to enable DARPA to initiate a new investment in less than 120 calendar days from idea inception. The model OT is representative of the terms and conditions that DARPA intends to include in all DO awards. The task description document, schedule of

milestones and payments, and data rights assertions requested under Volumes 1, 2, and 3 will be included as attachments to the OT agreement upon negotiation and award.

Proposers may suggest edits to the model OT for consideration by DARPA and provide a copy of the model OT with track changes as part of their proposal package. DARPA may or may not accept suggested edits. The Government reserves the right to remove a proposal from award consideration should the parties fail to reach an agreement on OT award terms and conditions. If edits to the model OT are not provided as part of the proposal package, DARPA assumes that the proposer has reviewed and accepted the award terms and conditions to which they may have to adhere and the model OT agreement provided as an attachment, indicating agreement (in principle) with the listed terms and conditions applicable to the specific award instrument.

DARPA's goal for this DO is to achieve an award within 105 calendar days from the posting date (March 13, 2026) of this announcement. To ensure that DARPA reserves the right to cease negotiations when an award is not executed by both parties (DARPA and the selected organization) on or before June 26, 2026.

III. Eligibility

Due to their specialized roles and longstanding regulatory relationships with the Government, Federally Funded Research and Development Centers (FFRDCs) and Government Entities to include National Laboratories present potential conflicts and advantages that would compromise fair and open competition. These entities typically may only receive funding through existing awards they hold with their sponsoring agencies. If these entities are proposed as subawardees, their costs must be clearly segregable in cost proposals. If scientifically merited, DARPA may fund work proposed by these entities, provided they: (1) clearly demonstrate that the proposed work is not otherwise available from the private sector; (2) FFRDCs must provide a letter, on official letterhead from their sponsoring organization, that (a) cites the specific authority establishing their eligibility to propose to Government solicitations and compete with industry, and (b) certifies the FFRDC's compliance with the associated FFRDC sponsor agreement's terms and conditions. DARPA, under this solicitation, will not award separate contracts to FFRDCs as prime or subawardees but will instead leverage their existing sponsors' agreements. Because of that, costs should be clearly segregable in submitted cost proposals.

While UARCs typically have statutory authority to compete with industry, internal DARPA policy views them as trusted advisors who are only eligible to act as performers in fields where they do not serve in an advisory role. Even in those situations, DARPA still considers UARCs as having organizational conflicts of interest (OCI) when applying for a performer role. Proposals with UARCs as prime or subawardees must include an OCI mitigation plan.

See Section 7 of DARPA-PA-25-07 for additional information on who may be eligible to respond to this announcement.

IV. Disruption Opportunity Responses

A. Proposal Content and Format

All proposals submitted in response to this announcement must comply with the content and format instructions in Section 5 of DARPA-PA-25-07. All proposals must use the templates provided as Attachments to DARPA-PA-25-07 and the "Streamlined Cost Buildup Workbook" Excel Attachment provided with this DO and follow the instructions therein.

Information not explicitly requested in DARPA-PA-25-07, its Attachments, or this

announcement may not be evaluated.

B. Submission Instructions

Responses to DARPA-PA-25-07-03 shall be submitted electronically to DARPA's Broad Agency Announcement (BAA) Portal (<https://baa.darpa.mil>).

DARPA will acknowledge receipt of complete submissions via email and assign identifying numbers that should be used in all further correspondence regarding those submissions. If no confirmation is received within two (2) business days, please contact CASTOR@darpa.mil to verify receipt.

When planning a response to this DO, proposers should take into account the submission time zone and that some parts of the submission process may take from one (1) business day to one month to complete (e.g., registering for a SAM Unique Entity ID (UEI) number or Tax Identification Number (TIN)).

Electronic Upload

First-time users of the DARPA BAA Portal must complete a two-step account creation process. The first step consists of registering for an extranet account by going to the URL above and selecting the "Account Request" link. Upon completion of the online form, proposers will receive two separate emails; one will contain a username, and the second will provide a temporary password. Once both emails have been received, the second step requires proposers to go back to the submission website and log in using that username and password. After accessing the extranet, proposers may then create a user account for the DARPA Submission website by selecting the "Register your Organization" link at the top of the page. Once the user account is created, proposers will be able to see a list of solicitations open for submissions, view submission instructions, and upload/finalize their submission.

Proposers who already have an account on the DARPA BAA Portal may log in at <https://baa.darpa.mil>, select this solicitation from the list of open DARPA solicitations and proceed with their submission. Note: proposers who have created a DARPA Submission website account to submit to another DARPA Technical Office's solicitations do not need to create a new account to submit to this solicitation.

All submissions provided electronically through the DARPA Submission website must meet the following requirements: (1) uploaded as a zip file (.zip or .zipx extension); (2) only contain the document(s) requested herein; (3) only contain unclassified information; and (4) must not exceed 100 MB in size. Only one zip file will be accepted per full submission. The DARPA Submission website will reject submissions not uploaded as zip files. Technical support for the DARPA Submission website is available during regular business hours, Monday – Friday, 9:00 a.m. – 5:00 p.m. Requests for technical support must be emailed to BAAT_Support@darpa.mil with a copy to CASTOR@darpa.mil. Questions regarding submission contents, format, deadlines, etc., should be emailed to CASTOR@darpa.mil. Questions/requests for support sent to any other email address may result in delayed/no response.

Since proposers may encounter heavy traffic on the web server, DARPA discourages waiting until the day submissions are due to request an account and/or upload the submission. Note: Proposers submitting via the DARPA Submission site MUST (1) click the "Finalize" button for the submission to upload AND (2) do so with sufficient time for the upload to complete prior to the deadline. Failure to do so will result in a late submission.

C. Proposal Due Date and Time

Proposals in response to this announcement are due no later than 4:00 p.m. on April 27, 2026. As described in Section 5 of DARPA-PA-25-07, full proposal packages must be submitted per the instructions outlined in this *DO and received by DARPA* no later than the above time and date. Proposals received after this time and date may not be reviewed.

Proposers are warned that the proposal deadline outlined herein is in Eastern Time and will be strictly enforced. When planning a response to this announcement, proposers should consider that some parts of the submission process may take from one (1) business day to one (1) month to complete.

V. Proposal Evaluation and Selection

Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-25-07. Proposers will be notified of the results of this process as described in Section 8.1 of DARPA-PA-25-07.

VI. Administrative and National Policy Requirements

Section 8.2 of DARPA-PA-25-07 provides information on Administrative and National Policy Requirements that may be applicable for proposal submission and performance under an award.

VII. Point of Contact Information

Michael McDonald, Program Manager, DARPA/DSO, CASTOR@darpa.mil

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this announcement must be emailed to CASTOR@darpa.mil. Emails sent directly to the Program Manager or any other address may result in delayed or no response.

All questions must be in English and must include the name, email address, and telephone number of a point of contact. DARPA will attempt to answer questions publicly in a timely manner; however, questions submitted within seven (7) calendar days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ list under the DO on the DARPA/DSO Opportunities page at (<http://www.darpa.mil/work-with-us/opportunities>). The list will be updated on an ongoing basis until one (1) week before the proposal due date.

For those new to DARPA or national security, DARPA makes available a free, comprehensive resource via DARPAConnect on how to do business with the agency. In addition to DARPA 101 materials, relevant preparatory modules includes “Understanding DARPA Broad Agency Announcements.” Registration and access are free at www.darpaconnect.us.

DSO has been using various solicitation formats to speed award timelines. These include Pitch Days, Advanced Research Concepts (ARC), and the accelerated award option for the Office-wide BAA. These are focused, milestone-based contracts designed to reduce negotiations and emphasize the quality of the idea and its potential for disruption over the proposer's ability to write a proposal. The milestone structure, where payment is tied to research execution rather than meeting aggressive metrics, is intended to incentivize ideas with high potential for disruption even if they are riskier. We are seeking feedback regarding these mechanisms from our proposer community. Please consider completing the survey at this link: <https://events.sa->

meetings.com/esurvey/126974