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EmPowering Innovation: The Gateway Power and Propulsion Element Public-Private Partnership

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Abstract

Leveraging NASA investments in advanced Electric Propulsion technology and 50 kW-class solar arrays, the Power and Propulsion Element (PPE) will be the first element of the cislunar Gateway. Recognizing the evolving capabilities and maturity of the space industry, NASA sought to understand through a number of industry studies and discussions, commercial capabilities and plans potentially aligned with NASA's capability and exploration needs as well as to help reduce risk for a new powerful and efficient Solar Electric Propulsion spacecraft. On May 24, 2019, NASA awarded a contract to Maxar Technologies to develop and demonstrate PPE as a novel public-private partnership. Targeted for launch in 2022, PPE will address both NASA and Maxar objectives. Maxar will own and operate PPE through launch and a demonstration period lasting up to one year. After the spaceflight demonstration, NASA will have the option to acquire the PPE for its use as the first Gateway element. This paper will provide an overview of the PPE development approach as a public-private partnership, fostering new and expanded commercial offerings as well as human return to the Moon and on to Mars.

Keywords: Artemis, power and propulsion element, cislunar gateway, public-private partnership

1. Introduction

Space Policy Directive-1 signed by the President on December 11, 2017, directed NASA to ''lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations'' [1]. In advancing this initiative, named Artemis after Apollo's twin sister and goddess of the Moon, Vice President Pence further charged NASA with landing the first American woman and the next American man at the South Pole of the Moon by 2024 followed by a sustained presence on and around the Moon by 2028 [2]. The Gateway Power and Propulsion Element (PPE), slated for launch in 2022, is being developed through an innovative public-private partnership (P3) and will serve as the first module of this new lunar infrastructure supporting human return to the lunar surface with continuing and sustained exploration of the Moon and on to Mars.

For NASA, PPE enables initial Gateway and crewed lunar surface operations with a sustainable presence in lunar orbit for expanded surface operations and extensibility for human Mars missions. As the first Gateway element, PPE will provide maneuvering capability between lunar orbits; attitude control; over 60 kW beginning-of-life power for electric propulsion (EP) as well as power transfer to other Gateway elements that will follow, providing for human habitation and science experiments; communications with Earth, visiting vehicles, and lunar systems; and accommodations for research payloads.

PPE and Gateway development status and plans, as well as PPE's role in NASA's Moon and Mars human exploration plans, are described in detail elsewhere [3, 4]. Instead, we seek to explain the approach and rationale for an innovative, pioneering spaceflight system acquisition and development. Specifically, this paper focuses on:

- the industry engagement by NASA used to inform PPE acquisition plans,
- the resultant novel P3 approach to PPE development addressing both NASA and industry partner objectives,

- implications and lessons learned for future acquisition, and
- the joint NASA/partner approach to managing the development and demonstration of this new and exciting stepping stone for space exploration and commerce.

2. Industry Engagement

To support NASA's Moon to Mars exploration objectives, NASA needs a highly reliable spacecraft bus capable of supporting the high-power, high-throughput, and high-propellant capacity solar electric propulsion (SEP) capability. At the same time, NASA recognized that the satellite industry has matured with a several decades-long historical record of spacecraft on-orbit performance. These spacecraft have evolved over the course of this span introducing new technologies, including SEP, to augment and eventually replace chemical propulsion for station keeping and maneuvering. The Boeing 702SP and Maxar SSL-1300/Eutelsat 7C are examples of all-SEP powered spacecraft.

In general, over the past several years the U.S. government has sought to leverage new and maturing commercial space capabilities using a variety of acquisition methods. In particular, a number of federal agencies, particularly the Department of Defense, have turned to using Other Transaction Authority (OTA) to mitigate lengthy traditional acquisition cycles and stimulate innovation [5,6,7]. NASA has similar OTA, commonly known as Space Act Agreements (SAA), under National Aeronautics and Space Act (Space Act), 51 U.S.C. sections 20101-20164 [8]. While OTA may be a useful and appropriate tool in many cases, the judicious application of a Federal Acquisition Regulations (FAR)-based acquisition approach may provide advantages, resulting in a timely and effective P3 arrangement [9].

A Broad Agency Announcement (BAA) is a solicitation method for Research and Development efforts based on synopses published on Federal Business Opportunities (FedBizOpps) that provide for full and open competition in accordance with FAR 6.102(d)(2) and merit-based, competitive procedures in accordance with the NASA FAR Supplement (NFS), Part 1835 [9,10]. BAAs are authorized for the acquisition of basic and applied research and that part of development not related to the development of a specific system or hardware procurement. The objective of a BAA is to encourage participation by science and technology firms and educational institutions in meeting NASA research and development goals for innovative ideas and approaches that are general in nature.

The Next Space Technologies for Exploration Partnerships (NextSTEP) omnibus BAA is a P3 contracting vehicle that NASA has utilized with great success since 2015. To date, NASA has awarded 57 separate contracts using the NextSTEP BAA.

Through the NextSTEP-2 BAA, NASA selected five U.S. industry-led studies for an advanced SEP vehicle capability. The studies helped define required capabilities, reduce risk, and identify the potential alignment of NASA needs and industry current capabilities and plans for a 50 kW-class SEP system. In November 2017, NASA awarded five 4-month contracts to study PPE SEP spacecraft concepts leveraging work begun under the cancelled Asteroid Redirect Mission (ARM). ARM had developed early design concepts for a 5,000 kg xenon capacity 50 kW-class SEP spacecraft bus, which would have been used to acquire a boulder from a near-Earth asteroid and transport it to cislunar orbit [11,12]. The PPE study participants, Boeing, Lockheed Martin, Orbital ATK (now Northrup Grumman Space Systems), Sierra Nevada Corporation, and Space Systems Loral (now Maxar Technologies), investigated differences from the ARM efforts and identified synergies between NASA plans for PPE and industry capabilities and plans. As a result, NASA determined that a 2,000 kg xenon capacity, 50 kW-class SEP spacecraft would meet NASA's needs for a Gateway PPE while allowing extensibility for NASA's Mars exploration goals and potentially aligning with industry's current offerings and plans.

In a separate BAA released on September 6, 2018, NASA specified only its unique requirements allowing the prospective partner the opportunity to complete the requirement set suiting their own specific interests. On May 24, 2019, NASA awarded a firm-fixed-price (FFP) contract to Maxar Technologies for the Spaceflight Demonstration of a PPE (Fig. 1).

Fig. 1. Maxar's notional PPE design

Maxar will own and operate PPE through launch and a demonstration period lasting up to one year. After the demonstration period, NASA will have the option to acquire the PPE for its use as the first Gateway element (Fig. 2).

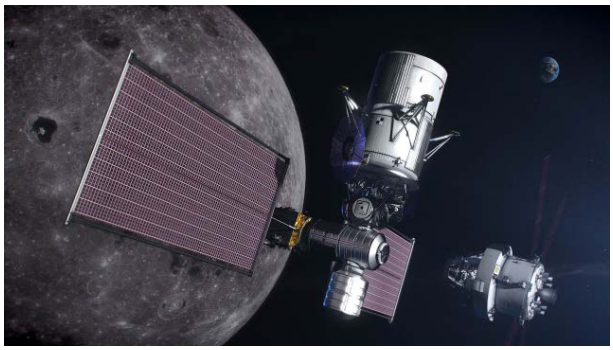

Fig. 2. PPE as the foundational element of Gateway

3. Procurement Approach

NASA has increasingly relied on P3s for achieving its strategic goals and objectives of expanding the frontiers of knowledge, capability, and opportunities in space. Such partnerships stimulate the U.S. commercial space industry while simultaneously delivering NASA-required mission capabilities at lower costs. This is reflected in the procurement approach implemented for the acquisition of the PPE. The Spaceflight Demonstration of PPE BAA, 80GRC018R0005, was developed as a full and open competition soliciting FFP proposals from United States industry that could lead to potentially one or more technology demonstration contract awards for an industry/NASA partnership for the development and spaceflight demonstration of a PPE [13]. Through one or more partnerships with U.S. commercial companies, NASA intends to demonstrate advanced technology of SEP that leverages U.S. commercially-available spacecraft bus capability that aligns with anticipated U.S. industry needs. The resulting demonstrated SEP system is intended to support both NASA and U.S. commercial future applications.

The BAA solicited proposals per FAR [9] 35.016(a) – Broad Agency Announcement (DEVIATED, Pursuant to FAR 1.403 – Individual Deviations) for one or more research and development contracts that included the option for NASA to own, as a specific system or hardware, the PPE spacecraft. The approved deviation included the ability for NASA to take ownership of the PPE as well as a deviation from FAR 35.005 – Work Statement to support the inclusion of some specific performance characteristics in a FAR Part 35 research and development contract. This approach was intended to allow Offerors the freedom to exercise innovation and creativity in their proposed approach to developing and demonstrating the PPE while also allowing NASA the option to own and use the inflight asset(s) for the Gateway after completion of the industry partner/NASA spaceflight demonstration. NASA considered use of a funded SAA; however, such OTA may not be used to acquire end goods or services.

The development of the PPE capabilities will be based on a joint set of industry partner and NASA unique requirements provided in the BAA solicitation as Attachment D – NASA Unique Requirements [13]. NASA purposely provided as part of the BAA only its unique requirements to allow industry the ability to propose a spacecraft that would also meet their needs for future commercial spacecraft applications.

The in-space demonstration of the PPE will be based on a joint set of industry partner and NASA demonstration objectives. The BAA was intended to result in a synergistic contractual arrangement with one or more industry partners to advance both parties' respective objectives.

Also as part of the procurement approach as well as the ability to streamline the procurement timeline, the BAA included a Model Contract with instructions to all Offerors to submit a signed hard copy of the Model Contract with their proposal. The government also communicated to industry its intent to evaluate and select for award, based on initial proposals, without discussions or negotiations. Accordingly, each Offeror was advised to submit its initial proposal to the government using the most favorable terms from a price and technical standpoint.

By design, multiple opportunities were created to ensure industry feedback throughout the acquisition process as early and as frequently as possible. This included utilizing the NextSTEP's BAA to conduct the 4-month industry studies concurrently with and informing the development of the acquisition strategy. A formal Request for Information (RFI) was crafted and released to request specific inputs needed from industry [14]. In June 2018, a draft of the PPE procurement BAA was released for industry review and comment. This was followed by an Industry Day in July 2018 that included opportunities to meet one on one with the PPE acquisition team and the NASA Center Points of Contact for discussion of possible Government Task Agreements. Even beyond Industry Day, communications continued per the External Communication Plan [13], which allowed up to two additional meetings with industry leading all the way up to the release of the Final BAA. The multiple opportunities to interact with industry proved out to be time well spent, gaining very valuable inputs leading up to the release of the final BAA on September 6, 2018.

One distinctive aspect of the procurement approach was that NASA defined only a subset of the overall PPE spacecraft requirements in the BAA. These "NASA unique" requirements defined the specific functionality that the PPE would need to provide as the first element of Gateway. As part of the partnership and commercialization approach, NASA allowed the Offerors to propose a spacecraft that allows them to demonstrate their functionality needs for future

commercial spacecraft applications. Consequently, the Offerors developed their own set of unique requirements and built a joint set of industry partner and NASA unique requirements. This integrated flight system requirements document was deliverable in draft form with the proposals and would continue to be managed by the industry partner after award. In addition, the Offerors were encouraged to propose augmented capabilities of value to NASA that exceeded the NASA unique requirements.

One of the main goals of the BAA was to allow Offerors to propose not only the use of their heritage spacecraft bus but also the use of their standard processes in order to take advantage of their proven reliability. NASA did not want to force Offerors to redesign their spacecraft or alter their production methods to create a unique product that would have resulted in reduced or uncertain reliability and incurred additional cost and schedule to produce. In conjunction with this approach, NASA required information from the Offerors as part of the proposal and after award to provide data justifying the use of their industry standards so that NASA could perform a risk assessment.

One of the areas this impacted was the approach to the use of Design & Construction (D&C) standards. NASA did not impose its D&C standards but allowed Offerors to use standards that they have typically used. The BAA did include a reference list of NASA D&C standards. As part of the proposals, the Offerors were asked to propose an approach to providing the data justifying the use of non-equivalent standards. After contract award, the industry partner is required to perform an equivalency assessment of their D&C standards relative to the NASA reference list. This assessment will include justification for the suitability of non-equivalent standards including relevant data on their past usage and other supplemental information that allows NASA to adequately assess the risk associated with their usage for the PPE. This will occur at the time of the baselining of the requirements and be delivered to NASA in the form of a Data Requirements Description (DRD) document.

NASA also provided a reference list of interoperability standards to aid Offeror's efforts in defining the PPE external interfaces with Gateway [15]. These included standards for avionics, communication, power, software, rendezvous systems, and external robotics. These were for reference only to avoid forcing the Offerors to redesign existing high-reliability commercial systems. The Offerors were required to include their interface requirements with the proposal and identify which interoperability interfaces that they propose to use that are equivalent or non-equivalent to those in the NASA reference list. After award, the industry partner will also provide an assessment of the PPE reliability benefits that result from each deviation from the reference interoperability standards in a DRD document. The Gateway mitigation approach is that future Gateway elements will be developed to be interoperable with the PPE where exceptions to the interoperability standards were proposed.

The last category of requirements addressed in the BAA were the Safety and Mission Assurance (S&MA) requirements. Similar to D&C standards and interoperability standards, the list of typical S&MA requirements used on NASA spaceflight missions was provided as reference only. In their proposals, the Offerors were required to describe the approach to provide data justifying the suitability of the Offeror's design concept for PPE where the design concept did not meet the reference list of S&MA requirements. After award, the Offeror is required to identify and assess the equivalency of their concept design with the reference S&MA requirements in a DRD document. For each reference requirement not met by their concept design, they will provide justification for the suitability of using that design including relevant data on past usage, reliability benefits, and other supplemental information that will allow NASA to adequately assess the risk associated with their approach.

From an Offeror's perspective, Maxar appreciated NASA's procurement approach for PPE, which was significantly more aligned with commercial procurement practices than traditional government procurements. Maxar believes that NASA will realize best value by taking this more commercial approach.

For Maxar, a key aspect of the PPE procurement process that was in line with a commercial approach was the numerous discussion opportunities that NASA provided in advance of the final BAA release. The four-month study period was critical for Offerors to develop their capabilities-driven approach and discuss it with NASA to determine where the Offeror's approach would meet NASA's needs and where it would fall short. Where it was determined that the approach would fall short, there was time to work with NASA to iterate the solution to come to a mutually beneficial conclusion. Additionally, the issuance of a draft BAA accompanied by significant discussion and the opportunity for one-on-one meetings provided an open dialogue to refine the procurement with NASA. This is in contrast to more traditional government procurement processes where the government may issue an RFI followed by a Request for Proposal (RFP) that contains volumes of detailed specification and process requirements. Once the RFP is released, there is a communications black-out period that prevents detailed discussions of the solicitation. This traditional approach tends to result in the Offeror making trade space decisions and optimizing to the RFP evaluation criteria which may not result in best value for either the government or the

Offeror. Commercial space best practices is to increase communications dramatically as the proposal gets closer and closer to submission. In a similar way, the study and one-on-one interaction approach taken on PPE meant that meaningful discussions could take place, maturing both the BAA and the Offerors' solutions in advance of the release of the final BAA.

Another key aspect of the procurement approach that is more in line with commercial standards is the use of a FFP contract. While NASA still required a Basis of Estimate (BOE) to support the proposed FFP proposal, Offerors were allowed to prepare the BOE in their own format which significantly streamlined the effort. The use of an FFP contract and the ability for Offerors to maintain their standard processes meant that PPE could leverage best practices from the commercial satellite industry.

For Maxar, another important feature of the PPE procurement was the P3. Establishing the P3 meant that NASA was willing to allow the Offeror, at the Offeror's expense, to include commercial Offeror-driven activities on the mission. This meant that the Offeror was able to realize increased revenue through PPE commercialization opportunities without detracting from NASA's mission needs.

Finally, Maxar greatly appreciated the incredibly fast contract signing which took place within one day of the contract award. This meant that the team could get to work right away on the important task of returning humans to the Moon.

4. Spaceflight Demonstration

The ultimate objective of the PPE P3 is to perform a spaceflight demonstration of the PPE. This means that Maxar retains ownership through launch and will operate the PPE for the first year of the PPE mission. During this time, Maxar will vet the capabilities of the PPE spacecraft, perform commercialization activities, and ultimately transfer the PPE into the Gateway Near-Rectilinear Halo Orbit (NRHO). At the end of the demonstration, NASA will have the option to take ownership of the PPE.

The PPE demonstration begins at launch and nominally ends with a handover of the PPE to NASA. The PPE demonstration mission is intended to perform a series of operations which will satisfy the joint demonstration objectives. The mission is broken down into four distinct mission phases (Fig. 3):

- Phase 1: Launch and Early Orbit
- Phase 2: Electric Orbit Transfer
- Phase 3: NRHO Demonstration
- Phase 4: Handover

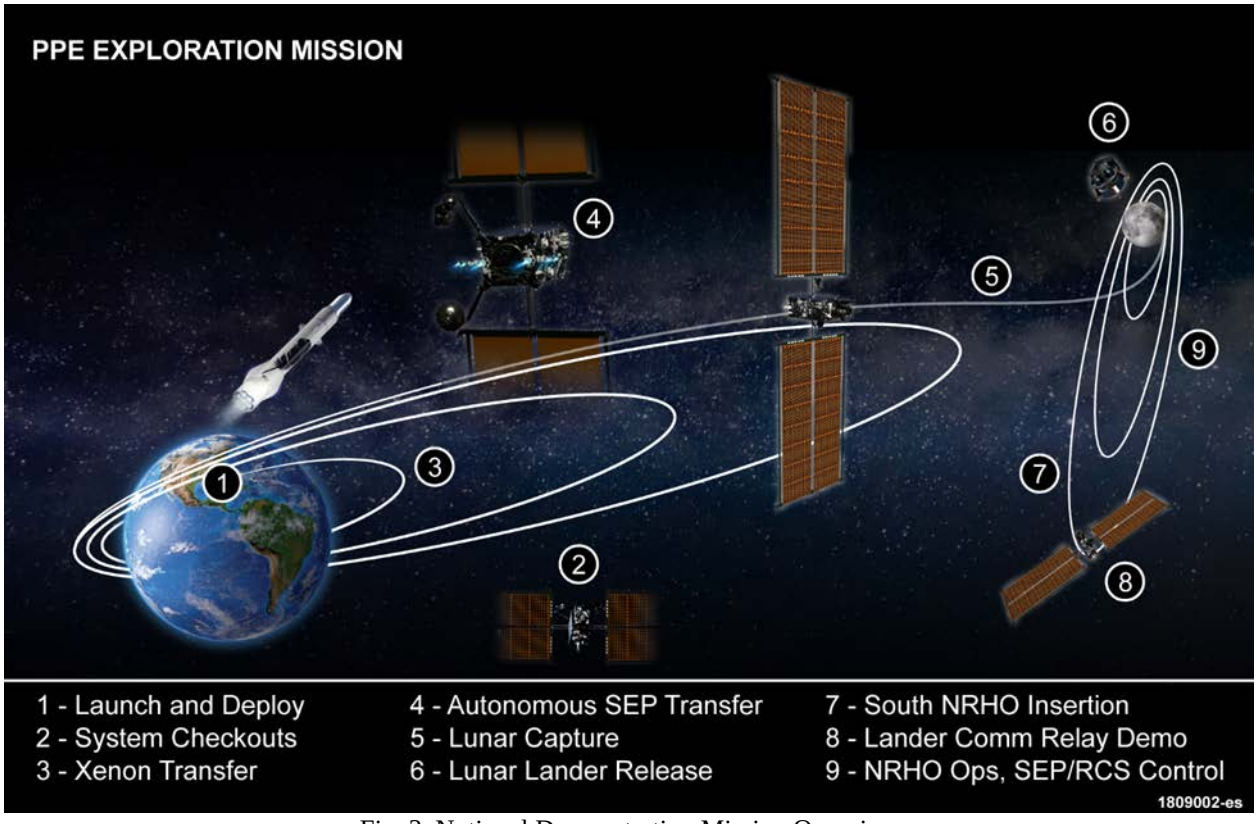

Fig. 3. Notional Demonstration Mission Overview

The Launch and Early Orbit Phase starts at the point of launch vehicle ignition and ends with completion of the In-Orbit Test. Activities in this mission phase include launch, separation, establishment of communications, deployment of the solar array and antennas, maneuvers to raise perigee, and then check-out of the bus, communications, power, propulsion, and data handling subsystems. This phase concludes with preparation activities for electric orbit-raising (EOR) including trajectory upload and orbit change verification. This phase is expected to take approximately 40 days.

The next phase is the Electric Orbit Transfer Phase. In this mission phase, high-autonomy EOR will be demonstrated, with the PPE gradually spiralling out from Earth orbit to the point of capture of the NRHO. During this phase, a significant amount of performance data will be collected, including telemetry data characterizing the EP system and data delivered by the on-board Plasma Diagnostics Package (PDP). It is likely that any rideshare payloads will be released during this phase. This phase is expected to take approximately 120 days.

The NRHO Demonstration Phase begins with the PPE entry into the NRHO. At this point other activities begin, including ranging and orbit determination at the Moon and checkout of lunar communications. The communications checkout may also include a demonstration of commercial communications relay services for commercial customers. This is followed by an operations checkout at the NRHO, which consists of characterization of the spacecraft performance in the local environment, and orbit control tests. This phase is expected to take approximately 130 days.

The schedule also includes approximately 60 days of contingency for additional data review or further characterization activities.

The Handover Phase is where the spacecraft team prepares to transition the PPE to NASA control if NASA decides to take ownership of the PPE at that point. This phase includes compatibility checks with NASA systems and tests with NASA controlling the spacecraft from NASA's mission operations centers to ensure smooth handover operations. This mission phase is expected to take approximately 15 days and completes the one-year demonstration mission.

With Maxar as NASA's PPE partner, NASA intends to demonstrate advanced SEP technology that leverages commercially-available U.S. spacecraft capability aligned with anticipated industry needs. The resulting demonstrated SEP system is intended to support both NASA and U.S. commercial future applications. NASA specific objectives for the spaceflight demonstration include the following:

- demonstrate high-power, 50 kW-class solar array and EP technology in relevant space environments,
- demonstrate continuous long-term electric propulsion operation sufficient to predict the xenon throughput capability and lifetime of high-power systems,
- demonstrate the deployment and successful long-term, deep space operation of high-power solar array systems with applicability to future higher power missions,
- characterize in-space operation of a next-generation EP string,
- demonstrate integrated SEP end-to-end system performance in relevant space environments,
- observe and characterize performance of integral high-power SEP system including thrusters, arrays, bus, and payloads as they operate as an integrated system and as they respond to the natural and induced in-space environments,
- demonstrate extended autonomous high-power SEP operations in deep space,
- demonstrate a high-data throughput uplink and downlink communication system using internationally-coordinated interoperability standards,
- demonstrate PPE insertion into a crew-accessible NRHO, and
- obtain design, development, and flight demonstration data to determine acceptability of the PPE for the Gateway.

Maxar brings the commercial demonstration desire to place their part in U.S. industry in an even better globally-competitive position "for a better world." (as their corporate purpose states) [16]. Some Maxar objectives for the PPE mission are to demonstrate high-power SEP capabilities for commercial communications satellites, demonstrate high-power SEP-enabled cargo transfer, and demonstrate next-generation commercial satellite servicing capabilities [17]. Achieving these commercial objectives will directly benefit NASA's Artemis missions and indeed improve humanity's understanding of the Moon and, through later extensibility of the resultant capabilities, our neighbor, Mars.

5. Future Extensibility

The technology developed for PPE has commercial extensibility applications both at the subsystem and the system level in the areas of commercial communications, commercial transportation, and commercial satellite servicing.

Maxar has maintained a leadership position in SEP by investing in the development of technologies,

including high-thrust/high-Isp Hall-effect thrusters, next-generation solar arrays, and advanced power processing units. These systems allow Maxar to offer more efficient, longer-life commercial communications satellites.

Through partnership with NASA on PPE, Maxar will have the opportunity to demonstrate cutting-edge SEP technology, integrated to create a highly-capable platform enabling next-generation, high-power communications missions. This platform provides significant opportunities for mission extensibility. High-power SEP will enable increased communications payload mass and power which translates into higher data throughput at lower cost, which will stimulate market demand. Specifically, flight demonstration of the Roll-Out Solar Array (ROSA), 6 kW EP thrusters, and a high-capacity xenon tank will provide the flight data and insights needed to position these technologies for ready adoption by commercial customers. These insights include evaluation of:

- data on advanced array performance trends under accelerated radiation exposure,
- life and performance of the high-efficiency, long-life, domestic 6 kW EP system, and
- performance of a high-capacity xenon tank in place of a traditional cluster of smaller tanks.

Maxar will integrate these subsystems into their commercial communications product line, so that they will enhance their traditional geosynchronous Earth orbit commercial communications satellite product. Additionally, with the advent of a commercial communications market at the Moon, Maxar will leverage the PPE capabilities to provide commercial communications services to the lunar marketplace.

PPE also has extensibility to commercial transportation services because of the high efficiency with which the PPE can transport large masses over long distances. Not only does a PPE-like tug have application to transport/transfer of spacecraft in Earth orbit, it also has application for commercial cargo transport between Earth's orbit and the Moon or Mars. As NASA moves towards a sustainable return to the Moon, a reusable hybrid chemical/SEP tug based on the PPE technology can provide a very cost-effective solution for cargo transport.

Further, PPE has extensibility to commercial satellite servicing activities. For example, development of the xenon refuelling standard for PPE will translate into similar standards for commercial communications satellites in Earth orbit. Additionally, a reusable hybrid chemical/SEP tug like PPE lends itself to transport of large quantities of propellant for refuelling of assets significantly beyond Earth orbit, such as at the Moon or Mars.

6. Lessons Learned

PPE developed and successfully executed a novel and compelling acquisition strategy. Lessons learned are being fed forward as acquisition approaches are being developed and instituted for other Moon to Mars elements. Specific lessons include:

- Careful consideration should be given to understanding the approach and basis for utilizing an existing commercial product to determine the appropriateness for use of a deviated BAA for other procurements.
- Full and open competition as a BAA and deviated FAR PART 35 approach resulted in a streamlined acquisition approach that resulted in very creative and innovative proposals.
- The BAA was successful in allowing for the inclusion and evaluation of industry's requirements and performance objectives, the provision of just the set of NASA unique requirements, and the ability to implement a P3 with industry.
- NextSTEP's study contracts enabled the Government's ability to inform the procurement strategy, understand commercial capabilities, and support a shorter proposal development timeframe.
- Inclusion of the Model Contract and requirement to submit a signed contract with the proposal significantly reduced the time between contract award and contract start to days versus weeks or months.
- Communications are highly encouraged and enabled per the use of both internal and external Communications Plans to have in place for use with both NASA internally and with industry to provide guidance regarding allowable communications prior to the final release of the BAA and the communications blackout that follows the release.

7. Gateway/Lunar Acquisition Approach

The PPE acquisition is a pathfinder for increased utilization of commercial capability in cislunar and deep space exploration operations as NASA intends to procure both Gateway and Human Landing Systems (HLS) elements through P3 mechanisms. NASA investment and expertise, joined with corporate capacity and capabilities, will further NASA's desire to become a marginal buyer of services rather than a sole proprietor and consumer of single-use systems. The P3 model is the keystone of NASA's overall acquisition strategy for the Moon to Mars exploration program [18]. It is imperative for NASA and industry to identify creative ways to leverage each other's strengths and core expertise in such a way that value is delivered to both parties. The mandate to return to the Moon by

2024 dictates that NASA pursue agile and responsive acquisition processes in order to meet schedule and cost goals. Harnessing the innovation of the aerospace industrial base and strengthening the space economy through partnerships provides an opportunity for NASA and industry to develop capabilities that meet NASA human space exploration objectives while also supporting industry's commercialization plans.

NASA has a demonstrated record of P3 success that stretches from the passage of the National Aeronautics and Space Act of 1958 [19] through commercialization initiatives such as Commercial Orbital Transportation Services (COTS), the Commercial Crew Program , and the Commercial Lunar Payload Services , to recently announced low-Earth orbit (LEO) Commercialization solicitations (NextSTEP-2 Appendices I, J, K) [20-25]. In June, 2019, NASA released the "NASA Plan for Commercial LEO Development [26]," in which the Agency outlined its strategy for incubating the space economy through increased opportunities for private sector ownership and operation of space infrastructure. NASA views industry as a partner, not just a supplier, in developing and delivering space exploration capabilities. Because the delivered capability, not the method of development, becomes the project driver, P3s enable the private sector to focus on the outcome-based economic value they are trying to create. P3s have become a legitimate and common capability delivery method, providing greater certainty of program cost and contract value before development begins, maximizing the use of private sector skills, and injecting private sector capital into space infrastructure. NASA views P3s as a way of introducing private sector technology and innovation to provide improved operational efficiency.

The separate, stand-alone BAA used to procure the PPE system has validated the flexibility and efficiency of this procurement methodology and highlights the importance of the P3 approach in NASA's Moon to Mars exploration enterprise. NextSTEP-2 is being used extensively in the Gateway and HLS development activities. NextSTEP-2, Appendix A "Habitation Systems," provides the construct for four U.S. companies to mature architectures and allocate functionality to a System Requirements Review–level of maturity for the U.S. Habitat element of the cislunar Gateway [27]. This work is focused on designing a robust, Mars-forward architecture that could be extensible to both deep space transport and surface habitation. A fifth company is pursuing the design, development, integration and test of a flight demonstration vehicle called the Habitat and Logistics Outpost (HALO), which will provide a minimal habitation and logistics capability to support initial lunar surface missions from the Gateway. The HLS program has engaged with eleven industry partners through NextSTEP-2, Appendix E "Human Landing System Studies" to mature human-rated landing technology and reduce risk in key areas [28]. On September 30, 2019, NASA released the final solicitation (NextSTEP-2, Appendix H) for the development, integration, and crewed demonstration of a lunar landing system by 2024 [29].

The objective of an award made under the NextSTEP-2 BAA is to provide recipients with the incentive to develop commercial applications of technologies developed through the partnership. Industry is incentivized by the requirement to provide corporate contributions in the form of internally-funded research and development and capital investment in return for increased commercial rights to the resultant technology. The P3 anticipates that the capabilities and technologies developed through these partnerships also will provide significant commercial applications beyond NASA. NASA's intent for awards resulting from this BAA is to enable P3s to exploit exploration capabilities and implementation of economic opportunities sponsored by, but not solely for the benefit of, NASA. The NextSTEP-2 BAA empowers the P3 model by engaging with industry throughout the solicitation development process so that commercial perspectives on functional requirements, intellectual property, data rights, test and certification and operational concepts are considered and incorporated as appropriate in the final solicitation and contract.

8. Conclusions

NASA is seeking to leverage emerging commercial capabilities and plans to advance exploration objectives of landing the first woman and next man on the Moon by 2024. PPE's commercial partnership approach aligns well with U.S. policy as defined in SPD-1. In the innovative, FAR-based acquisition approach, NASA allowed an industry partner room to implement their goals and objectives on top of NASA's requirements for mutual benefit.

What does this mean as a practical matter for Gateway, Human Lunar Landers, Mars exploration, and NASA's international partners? PPE has pioneered a novel approach bringing commercial partners, from the start, into our deep space adventure. NASA is utilizing this approach, along with lessons learned, in plans for acquisition of other human exploration elements. P3's such as PPE will help build a sustainable program extending human presence on, around the Moon, and to Mars.

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