ISS Space-to-Space Power Beaming: Fostering a Cislunar Electrical Power and Ancillary Utilities Service

Phase 1: Technology Development

Proposal for
ISS National Lab Resource Allocation and Mission Development Funding
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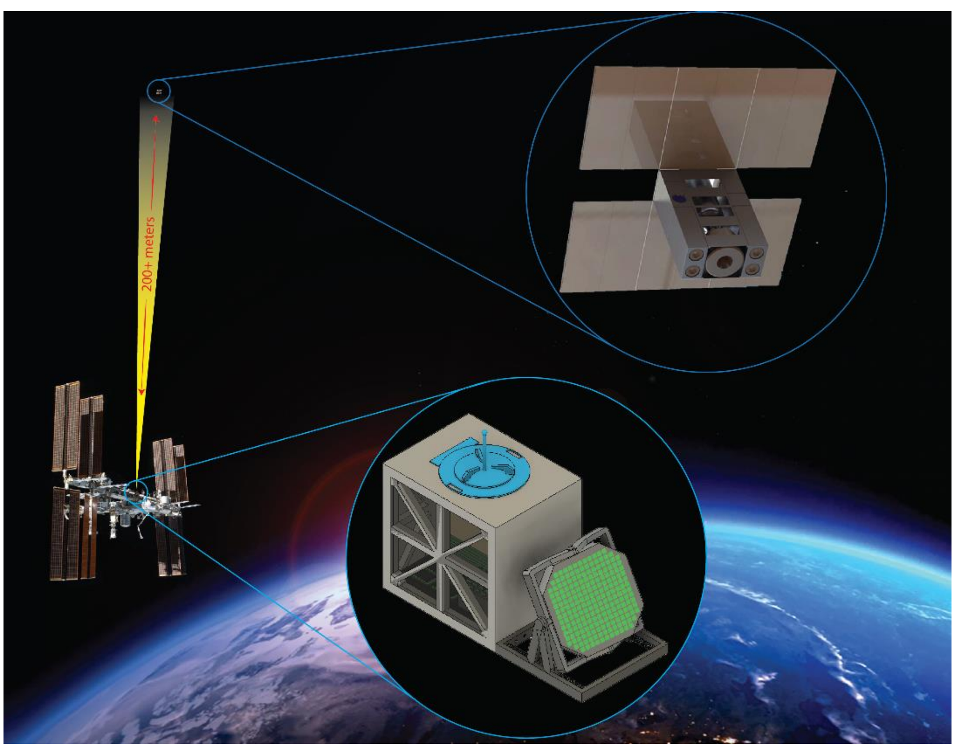

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2.2 Abstract

This proposal is for a focused technology development mission for Space-to-Space Power Beaming (SSPB), to be implemented on the International Space Station (ISS). The SSPB mission builds on foundational research in the field as well as mission development work accomplished to date by the proposed Principal Investigator (PI), XISP-Inc, and the XISP-Inc SSPB Consortium participants. The overarching objective of this mission is to hasten the development of viable applications of SSPB technology and ancillary services through focused incremental efforts that bridge the technology development "valley of death" as well as substantially mitigate perceived and actual cost, schedule, and technical risk associated with applications of the technology. The SSPB mission objectives include the technology development necessary to support the unbundling of a commercially relevant space power system (i.e., the separation of power generation, transmission, distribution, and loads) along with the multiplexing of ancillary services (e.g., data, communications, navigation, time) to enable Space-to-Space and Space-to-Alternate Surface power beaming, and support the evolution of Space-to-Earth power beaming.

The first phase (Phase I) of the SSPB mission is technology development. This includes lab/ground test work (XISP-Inc & teammate Internal Research and Development (IRaD) and leverageable contract research & development) which will transition into highly configurable space-qualified instances of Software Defined Radio (SDR) transceivers, rectennas, and related control systems. These elements will have mutable/switchable apertures (frequency-agnostic radiant energy beaming source), separate and converged conformal rectenna/solar array/antenna constructs that are configurable/tunable (combination of phased array, reflectarray, and multi-layer/junction, and related technologies), and software-driven controls. The elements will be integrated to form an on-orbit testbed consisting of an ISS-based transceiver, a co-orbiting CubeSat flight test article, and related management operations control applications. The testbed will support the near–real-time characterization, optimization, and operationalization of an unbundled power and ancillary services beaming system.

Use of the ISS significantly reduces the cost and complexity of the proposed mission. The total estimated time to complete Phase I is 16 months, with a budget estimate (both cash and in-kind) of approximately $7 million. Of this budget, $250 thousand is requested CASIS mission development funding plus CASIS integration partner costs. XISP has received conditional letters of support from capital funding sources committed to provide the balance if support from CASIS gives the SSPB mission recognizable standing.

The ability to provide power and ancillary services when and where needed is essential to virtually all aspects of human endeavor and enables all forms of space development/settlement. The SSPB missions will deliver significant commercial value in the form of power and bi-directional ancillary services to a growing number of customers interested in co-orbiting with the ISS and lay the foundation for a myriad of Cislunar applications. Furthermore, space solar power technology holds the promise of being one of the few large-scale energy generation options that can scale upward to meet the growing electrical energy demand both for space and for terrestrial applications worldwide. This mission is a unique opportunity to foster the development of space-to-space power beaming, by leveraging ISS resources to create a SSPB testbed environment on and near the ISS that supports the development of frequency-agnostic radiant energy beaming technology.

2.3 Technical Section

2.3.1 Detailed Project Plan

<u>Research Questions & Significance</u>

XISP-Inc has hypothesized that unbundling power systems (i.e., the separation of power generation, transmission, distribution, and loads) can reduce spacecraft complexity, mass, and volume, thereby reducing the cost, schedule, and technical risk of a given mission. SSPB can also foster the development of loosely coupled modular structures to enable:

- Formation flying of multiple spacecraft (e.g., interferometric groups, swarms)
- Distributed payload and subsystem infrastructure to simplify the accommodation of multiple plug-in and plug-out interfaces
- Large scale adaptable space structures that minimize conducted thermal and/or structural loads.

The SSPB mission objective is to test the hypothesis by creating a viable design for a Space-to-Space Power System that is cost-effective, scalable, and readily extensible to multiple applications. The SSPB mission phases will result in a significant advancement of the technology's maturation from TRL 4 to 8/9. Such SSPB systems must accommodate key service variables for which the optimization varies with each addressable market:

- Frequency/Wavelength (microwave to eye-safe optical),
- Distance (near field, boundary regions, far field),
- Magnitude (i.e. power level supporting non-weaponization and peaceful use [individual end-user scale <10 kW, industrial scale 10 kW to 100 kW, military scale > 100 kW]),
- Duration (pulse, scheduled, continuous),
- Availability (on demand, scheduled, prioritized, by exception),
- Security (misuse, interruption, destruction), and
- Performance (net transfer, end-to-end efficiency, piecewise efficiency, effective difference).

<u>Innovation</u>

There is no technology currently available that can allow separation of solar arrays from other spacecraft systems (e.g., the sensor package, pointing/mobility systems, or communication equipment). State-of-the-art beamed power systems for space applications are at TRL 4. This work will develop the first Space-to-Space radiant energy beaming testbed to support the characterization, optimization, and operationalization of space solar power radiant energy beaming technology and the proposed follow-on demonstration will be the first-ever commercial system test of in-space beamed power, advancing this technology to TRL 8/9. This includes the development and in situ verification of the following:

- Near–real-time state models of the radiant energy beam components,
- Beam forming characteristics and variation in performance with frequency (Ka Band, W Band, other higher) and distance (near field, boundary, and far field),
- End-to-end and piecewise beam efficiency.
- Differential rectenna response, rectenna geometry variation, optimization metrics by application, and operational rules for deployment will also be tested and verified.

Table 1 outlines the proposed SSPB mission innovations and benefits compared to the current state of the art.

Mission type	System Options, State of the Art	Unique Benefit of Beamed Power
ISS co-orbiting crew-tended free-flying laboratory / manufacturing space	• Not available. Fault- tolerant utilities and an evolved concept of operations are required.	• Repurposes pressurized logistics carriers at low cost • Can provide additional level of utility failure tolerance • Can provide power augmentation needed for experiments
Asteroid / Lunar / Martian surface activities (dust in a “cloud” and also settling on surfaces)	• Electrostatic “wipers” to clear surfaces • Cables to bring power from remote generation • Large batteries • Large solar arrays to accommodate shading losses • Nuclear power	• Beam frequencies penetrate dust, increasing system end-to-end power collection efficiency • Reduced mass and volume of deployed rovers/surface equipment • “Wipers” are ineffective against strong dust chemical / physical adhesion; elimination increases reliability and reduces maintenance • Reduced system and logistic complexity, and increased safety, relative to nuclear options
Dark craters, crevasses, lava tubes and areas of extended eclipse duration	• Large batteries • Cables connecting to remote power generation site • Operational limits on activity time, power consumption • Radio-isotope heaters	• Lower mass and volume of rovers relative to long-life batteries • Removal of cables increases reliability and improved system safety, while also removing operational constraints • Minimal operational limits and constraints allow continuous, long-duration operations for increased equipment utilization efficiency • Reduced system and logistic complexity, and increased safety, relative to nuclear options
Disaggregated systems in Earth orbit	• Each element carries solar arrays • System design constraints avoid sun-shadowing • Avoid disaggregation by using small numbers of spacecraft	• Receiving rectenna on each element is significantly smaller than solar arrays due to higher received power density and greater conversion efficiency, resulting in lower mass and volume of each element and decreased atmospheric drag in LEO • Lower cost to upgrade the elements with new and/or different sensor and communications capability because the power generation system does not need to be replaced • No sun-shadowing constraints, so that system and logistic complexity are reduced • Large numbers of small elements in a disaggregated system provide increased reliability and resilience relative to smaller numbers of larger elements
Sensor platforms with demanding spacecraft dynamics or thermal / structural loads	• Solar arrays • Attitude control systems with sufficient control authority • Thermal stand-offs	• Receiving rectenna significantly smaller, with greater conversion efficiency (reduced mass, volume, inertia, stiffness, and thermal load) than sensor platform solar arrays • Smaller sensor platform attitude control actuators (reduced mass, volume, power requirements) • Simplified thermal and structural design of the sensor platform • Orbit can be optimized to sensor requirements by removing constraint of solar array pointing
Large power consumers in Earth Orbit (e.g., ComSats)	• Carry large PV arrays, currently less than 40kW	• Moving power generation on the ComSat balance sheet from CapEx to OpEx • On the Power Utility balance sheet, amortize investment over the life of many satellites, and many generations of satellites • Decouple ComSat earth-pointing and station-keeping requirements from power generation sun-pointing and eclipse avoidance requirements • Economies of scale in the power generation equipment, as one power generation satellite can service perhaps 100 ComSats

Table 1 - Unique Benefits of Space-to-Space Power Beaming vs. the Current State-of-Art

<u>Why the ISS</u>?

The SSPB mission needs all components of an end-to-end power system in space in order to accomplish the mission objectives. More specifically, it requires:

- A source of readily available power (ISS Power System),
- A stable platform for mounting and operating a transmitter (ISS JEM Exposed Facility) with a clear view facing RAM, starboard with a zenith bias,
- Persistent exposure to the low Earth orbit environment (e.g., vacuum, atomic oxygen, radiation, debris, hot/cold cycling, and microgravity) duplicating the actual intended operational environment (ISS environment).
- All of the above, to provide a suitable vantage point for an aerospace testbed for TRL-raising applications for space solar power technologies.
- The ISS serves as a proof-of-concept platform for evaluating the potential for building and operating a space-based power and ancillary services utility, and
- The ISS reduces the cost and complexity of SSPB missions and the resulting infrastructure enables routine use of ISS co-orbiting free-flying spacecraft.

<u>Related Work</u>

Section 7.1 contains an extensive set of prior work references, and Section 7.2 provides a listing of the Principal Investigator's selected publications, presentations, papers and collaborations with other SSPB experts.

<u>Timeline and Success Criteria</u>:

The proposed SSPB mission milestone schedule is shown in Table 2 – XISP-Inc SSPB Phase I Timeline Milestone Chart. The top level success criterion is the accomplishment of the milestones listed. More specifically, the mission shall:

1. Complete the Mission Development, detailed design, and make/buy parts out of the SSPB mission components.
2. Complete the Form, Fit & Function Ground Test and analysis for the SSPB mission components.
3. Complete the Protoflight Ground Test and analysis for the SSPB mission components.
4. Complete the final build and deliver of the SSPB mission components for launch integration.
5. Achieve successful launch and delivery of the SSPB mission components as commercial cargo to the ISS.
6. Complete the installation and integration of the SSPB mission components with the ISS.
7. Activate the SSPB testbed and repeatedly exercise the ability to provide a near–real-time characterization of the radiant energy beam and the end-to-end system, capturing all relevant performance, availability, and security data.
8. Repeatedly exercise the ability to optimize the radiant energy beam to tune the piecewise efficiency of the beam and the end-to-end system, capturing all relevant performance, availability, and security data.
9. Repeatedly document the ability to operate the SSPB testbed in full conformance with prevailing ISS operational rules, procedures, and guidelines.
10. Demonstrate the use of the testbed to deliver power and ancillary services to a payload deployed on the SSPB co-orbiting small satellite flight test article.

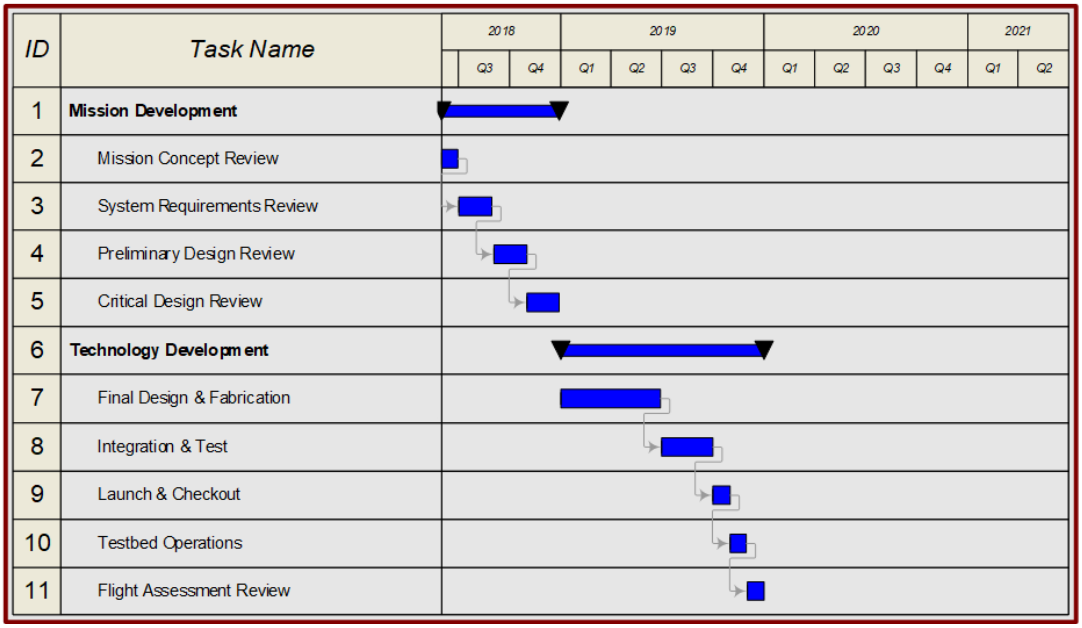


Table 2 – XISP-Inc SSPB Phase I Timeline Milestone Chart

Risk Mitigation:

The main risks to the SSPB mission arise if the new flight components (as described in the Operational Approach Section) are not successfully built, deployed or operated. These risks and mitigations are as follows:

Satellite Bus/Subsystems: Activation and control of the satellite bus and its proximity to ISS poses a risk. The activation risk is the satellite bus will be deployed RAM, Starboard or Port, with a Zenith bias with an initial non-zero velocity, the system must activate to assume a station-keeping position co-orbiting with the ISS just outside the Keep Out Sphere of 200 m. The control risk is the need to accommodate ISS Attitude Control System adjustments on an as needed basis. The proximity risk is given that ISS is constantly losing altitude except during reboost maneuvers, regardless of the operational state of the satellite bus after its deployment, the ISS will be in no danger of colliding with it. The mitigation of these risks requires a two fault tolerant activation and control system and sufficient propellant reserves. The resulting dwell time for an ISS-based beam would be limited by the ability of the satellite bus active Attitude Control System/Propulsion system to maintain position.

ISS Transceiver & Apertures: The successful activation of deployable apertures with a total surface area of one square meter or less is well within the operational envelope of previously installed ISS systems. The risks associated with the activation and operation of the transceiver are expected to be mitigated by high fidelity ground testing/modeling.

Rectenna: The ability to produce a rectenna with optimized performance for the full range of frequencies of interest is a significant area of technical, schedule, and cost risk. It is anticipated that the mitigation strategy will be to accept a satisfactory and sufficient design bounded by experiment (i.e., be frequency agnostic within certain defined limits) rather than force the optimization to a specific frequency from the start of the mission that could inadvertently overshoot or undershoot what is achievable.

Radiant energy beaming control and safety interlock system: This system will use the XISP-Inc Management Operations Control Applications (MOCA) – (XISP Xlink near–real-time state model extended NASA ARC Mission Control Technologies OpenMCT software suite), and an IPv6 Delay/Disruption Tolerant Networking (DTN)-enabled implementation of WAVElan SECurity using IPsec (WAVESEC) compatible with the Immortal Data Inc. Shipslog

Data Capture and Analysis system. Unless the WAVESEC link is established, authorized, and validated, outbound transmitter power will be inhibited to a minimum sensible level. This technology has been used in other terrestrial applications, but use for SSPB is a novel application. The mitigation for this is additional crew and/or ground control time associated with the actuation of additional manual inhibits.

Operational Approach:

This XISP-Inc SSPB mission concept of operations is summarized in Figure 2. This proposal and the operational concept are focused on the Phase I technology development phase:

- ISS transceiver transportation and location on JEM EF
- Satellite Bus (6U CubeSat Flight Test Article) transportation to ISS and release into ram-starboard position with zenith bias relative to ISS
- Demonstration of radiant energy beaming between transceiver and 6U CubeSat. The CubeSat will be outside the 200m ISS spherical zone of exclusion and at a maximum distance of 1 km during testbed operations.

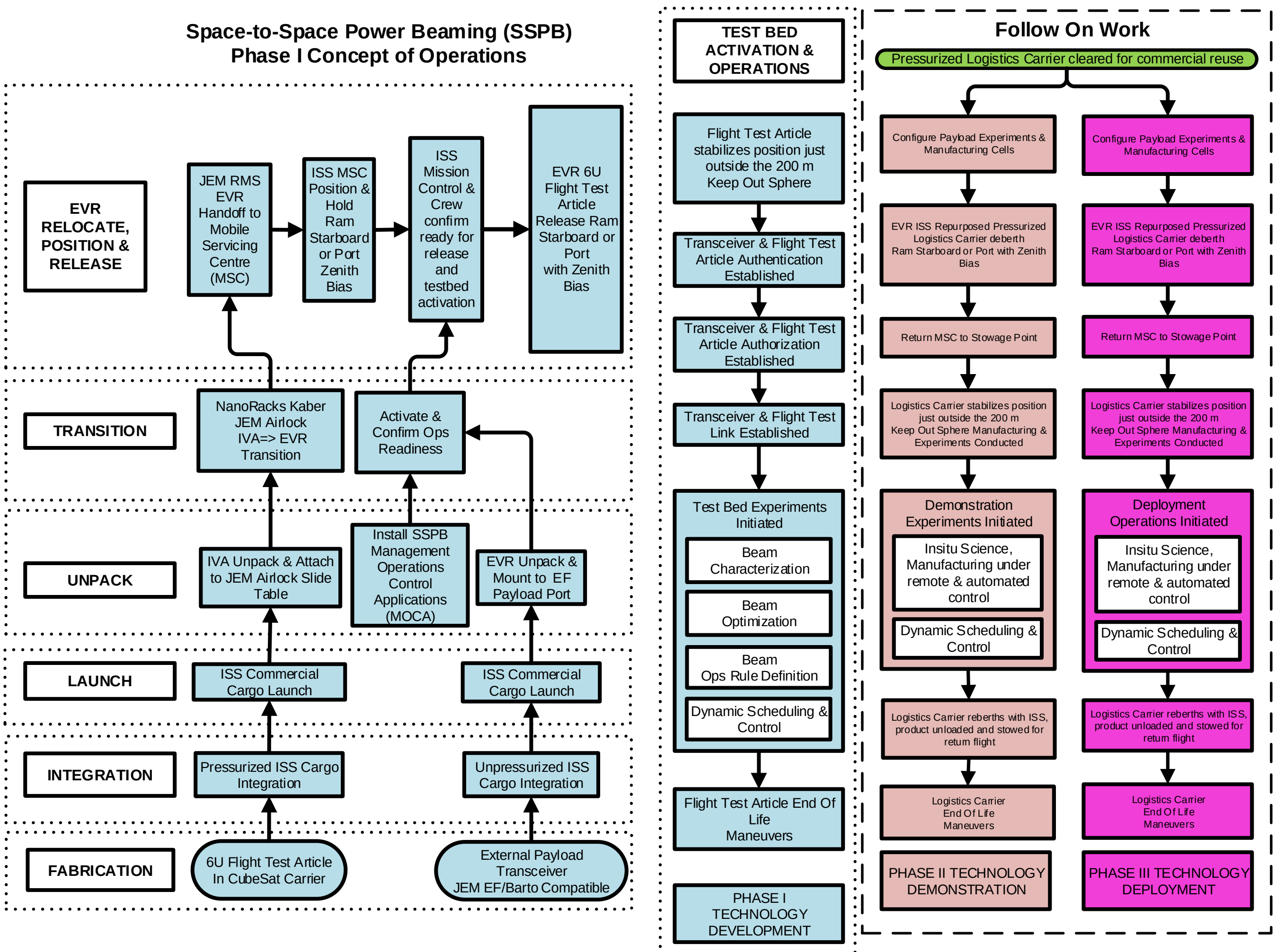


Figure 2 – SSPB Mission Phase I Concept of Operations

The space-based hardware, design and operation and are further described in detail in the following sections.

ISS Transceiver

Illustrations of the proposed ISS transceiver are shown in Figure 3. The baseline ISS transceiver is an evolved Raytheon IRaD product to be infused with the Tethers Unlimited, Inc. Swift SDR enhancements which include waveform library & electronics slice adjustments to suit bi-directional multiplexing, retro-direction, and compliance with ISS Electromagnetic interference (EMI), electromagnetic compatibility (EMC), and Electromagnetic Environmental Effects (EME) requirements.

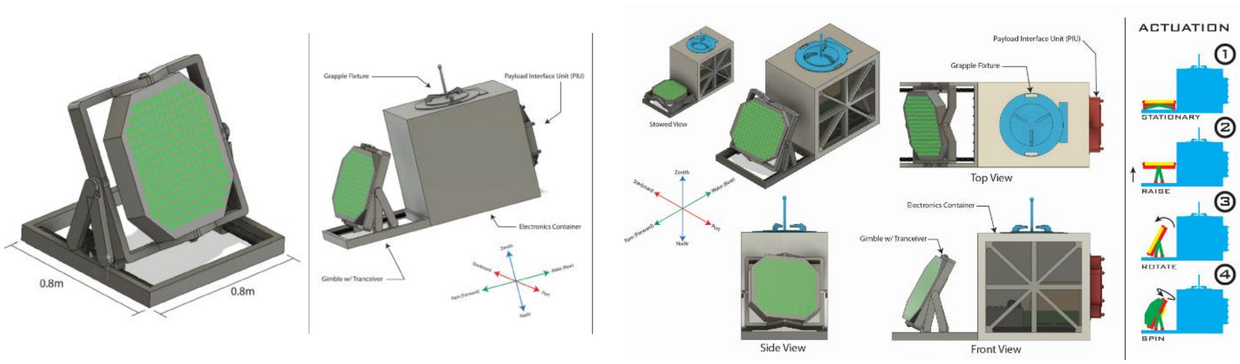


Figure 3 – Illustrations of ISS Transceiver for XISP SSPB Operation

The ISS transceiver will be similar to the AFRL/Raytheon 95 GHz phased array antenna aperture and will fit within the JEM Exposed Facility Payload Carrier envelope. The design incorporates all required EVR, JEM Exposed Facility, and Columbus Bartolomeo (Barto) interfaces. The transceiver will be launched to ISS as an unpressurized cargo item in the SpaceX Dragon “Trunk” (or a JAXA HTV-X) with payload removal by the MSC and hand off as needed to allow installation on the JEM Exposed Facility. This is now a routine EVA Robotics (EVR) operation.

- The combined mass of the transceiver and the payload carrier with required interfaces will be less than or equal to 500kg.
- The total volume of the transceiver and the payload carrier with required interfaces will be less than or equal to ~1.44 m^3 (1m x 1.8m x .8m).
- The maximum input power drawn if the use of one Remote Power Controller is authorized will be up to 3 kW, 113-128 VDC on a scheduled basis. The estimated actual power draw for testbed operations based on anticipated efficiencies and the thermal limitations of the 6U CubeSat flight test article is less than 300 W. The duration and frequency of operation will be dynamically schedulable based on power availability.
- For Phase II/III operations the maximum input power draw if the use of two Remote Power Controllers is authorized could be up to 6 kW, 113-128 VDC on a scheduled basis. The duration and frequency of operation will be dynamically schedulable based on power availability.
- A low-rate data connection to the 1 Mbps (MIL-STD-1553) bus will be available.
- A high-rate data connection to the 43 Mbps (shared) Ethernet 100 Base-TX payload network will be available.
- A high-rate data connection to one or more wireless networks may also be available

The transceiver with one or more deployable apertures with a surface area of one square meter or less will be electrically and mechanically inert until successfully attached to the EF utility port and the utility port power/data connections are activated. This is well within the operational envelope of previously installed ISS systems. Since the EMI/EMC requirements mandate full conformance with prevailing ISS rules, procedures, and guidelines, any risk associated with the operation of the transceiver will have already been dispositioned by ground test and analysis. Given that all transmissions will be away from the ISS towards unobstructed space, no unique risks are imposed with operation of this component.

While there are multiple other sources for the ISS transceiver, Raytheon is an extraordinarily compelling choice as the company is a pioneer and leader in microwave technology and have granted XISP access to their intellectual property. Raytheon is a committed and active member of the SSPB Mission Consortium.

Satellite Bus (6U CubeSat Flight Test Article)

The XISP non-toxic satellite bus will be similar in design to the Alpha Cube Sat (ACS) PDR design shown in Figure 4. The satellite bus is Extra Vehicular Robotic (EVR) deployable, with H_2O-based active Attitude Control System/Propulsion thrusters, integrated with SDR including a task-appropriate waveform library and multiplexing capabilities, and will use reflectarray solar array/rectennas. Its total surface area is less than one square meter.

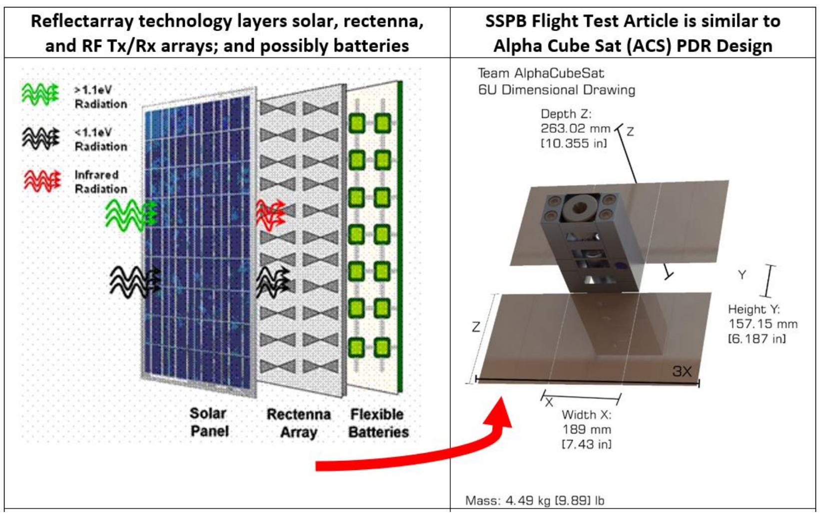


Figure 4 – XISP Satellite Bus will be of similar design to 6U Alpha Cube Sat on the right side of the figure. Layered reflectarray technology on left will replace the solar panels.

The satellite bus will be launched as soft packed pressurized cargo preloaded into an EVR compatible Planetary Resources standard deployment container. The container will be integrated with the NanoRacks, Inc. Kaber EVR interface on-orbit by the ISS crew and deployed through the JAXA Kibo lab airlock. EVR resources (JEM RMS and/or MSC) will be used to relocate and deploy the satellite bus under ground control.

- The baseline Satellite Bus is the Blue Canyon Technologies XB Spacecraft.
- The flight test article will be an instance of the Alpha Cube Sat design, constructed from the vendor's COTS flight qualified systems/subsystems with the following exceptions/modifications:
  - Rectenna overlay, a separately developed item supplied* by Raytheon, Inc.
  - SDR Transceiver - Communications System supplied* by Tethers Unlimited, Inc.
  - H_20 Thruster - Propulsion System supplied* by Deep Space Industries, Inc.
  - Data Capture & Analysis Subsystem supplied* by Immortal Data, Inc.

  (*Technical, cost, and/or schedule considerations could alter the anticipated suppliers.)

- While there are multiple other satellite bus alternatives that have been identified as technology, cost, and schedule risk mitigation measures, Blue Canyon Technologies' industry leading product and supporting systems/subsystems, commitment to be an active part of the SSPB Mission Consortium and demonstrated commitment to space development makes them a compelling choice.

- The mass of the 6U Satellite Bus portion with a full complement of systems/subsystems, including an integrated deployable reflectarray solar array/antenna/rectenna, is approximately ~14 kg.
- The total mass of the flight test article integrated with flight support equipment is ~40 kg, assuming the use of a Planetary Resources deployment canister with the integrated satellite installed on the ground.
- The deployment canister will be wrapped in bubble pack, surrounded by foam. and stowed in a standard soft pack cargo bag for launch in a pressurized logistic carrier to the ISS.

SDR Transceiver - Communications System

The baseline SDR Transceiver – Communications System for satellite bus is the Tethers Unlimited, Inc. Swift SDR. While there are several other COTS SDR alternatives that have been identified as technology, cost, and schedule risk mitigation measures, Tethers Unlimited, Inc.'s industry leading product, commitment to be an active part of the SSPB Mission Consortium and demonstrated commitment to space development makes them a compelling choice.

H_20 Thruster - Propulsion System

The baseline H_20 Thruster - Propulsion System – for the technology development flight test article is the Deep Space Industries, Inc. Comet H_2O thruster/propulsion system. While there are several other H_20 Thruster - Propulsion System alternatives that have been identified as technology, cost, and schedule risk mitigation measures, Deep Space Industries, Inc.'s industry leading product, commitment to be an active part of the SSPB Mission Consortium and demonstrated commitment to space development makes them a compelling choice.

Baseline Rectenna

The baseline rectenna for the technology development flight test article is an evolved Raytheon IRaD product to be infused with the SSPB Mission Consortium derived technology enhancements. Secondary supporting vendors and university researchers have been identified and engaged as technology, cost, and schedule risk mitigation measures to allow for the parsimonious use of Raytheon resources.

Data Capture & Analysis System - Data System Overlay

- The baseline Data Capture & Analysis System – Data System Overlay – for the technology development flight test article is the Immortal Data, Inc. Shipslog product line.
- Data collection will be performed by a customized implementation of the Immortal Data Shipslog Suite with headless elements attached to the ISS payload network via wired, Wi-Fi (802.11 AC), and/or RF (direct or relayed) connections. This will address data collection from the ISS transmitter, the active ISS payload workstation, the deployed 6U CubeSat for testbed operations, and the ISS reference time & telemetry markers. (See Figure 1).
- This system includes all the necessary sensors, augmented processing as well as storage capability, and bus control logic to ensure all generated data is captured and made available for both near real-time analysis and extended analysis on the ground.
- A near–real-time state model of the SSPB testbed will run continuously on mission-provided resources. The model will be served up as a web page available on demand to any workstation on the ISS payload network for ISS observation, monitoring, and control, and will be made available to support ground observation, monitoring, and control.
- This work will require the implementation of Management Operations Control Applications supporting interfaces with the Flight Test Article Satellite Bus Data System, the Flight Test Article Rectenna, the ISS Transceiver, an ISS Payload Network laptop, as well as virtual interfaces with the ISS Payload Network, ISS Flight Operations Center, ISS Payload Operations Center, and the XISP-Inc Remote Payload Operations Center.
- While there are multiple other vendor alternatives that have been identified as technology, cost, and schedule risk mitigation measures, Immortal Data Inc.'s evolving industry challenging product line, active role in XISP-Inc mission development, commitment to be an active part of the SSPB Mission

Consortium, and demonstrated commitment to space development makes them a compelling choice.

Hardware Development Timelines

Vendor-quoted timelines for the SSPB Mission Phase 1 Commercial-Off-The-Shelf (COTS) components are less than 3 months for test hardware and less than 6 months for delivery of the flight hardware components.

The work on the customized components will start by establishing a baseline of what is currently available and known to function from SSPB Mission Consortium members. In addition, a set of proposed enhancements for each component will be identified to increase the performance that can be developed with an acceptable level of cost, schedule, and technical risk (i.e., from vendors with existing product, vendors/labs with analogous product, and vendors/labs with potentially viable prototypes). A "bake off" will be defined and kicked off in the beginning of the next phase of mission development, and will culminate in final selections being made based on the testing results at the end of the Mission Development Phase. It is anticipated that the competitive process could take up to 6 months, and the delivery of the customized components could take up to an additional 6 months. While the timeline for the production of the customized components can be decreased to perhaps as short as 3 months total, it is anticipated that achieved performance will be improved by a period of focused technology development.

Satellite Bus/Subsystems: Using a combination of the XISP-Inc Alpha Cube Sat preliminary design (see Table 12 -- SSPB Mission WBS Element Technology Readiness Level) and the integration of lightly tweaked COTS components, it is anticipated that procurement of the required flight test article will be a tractable task. The verification approach will be by similarity and test. COTS detailed schematics and engineering drawings are available for the Satellite Bus and all subsystems. It is anticipated that ground test articles will be available within 1 month of order, protoflight within 3 months of order, and the final flight article no more than 6 months from the time of order.

Rectenna: The successful development of a deployable reflectarray solar array/rectennas attachable to a 6U CubeSat with active attitude control and H_2O propulsion, having a total surface area of one square meter or less, while challenging is not intractable given sufficient high fidelity ground testing/modeling. However, experiments will have to be conducted to determine how far up the available frequency spectrum it is possible to go while still retaining acceptable conversion efficiency. The ability to produce a functional rectenna is not at issue, but optimizing the performance is. The ability to produce an optimized rectenna to purpose is a significant area of technical, schedule, and cost risk. To mitigate this risk, the SSPB mission will be frequency agnostic with the intention to accept a satisfactory and sufficient rectenna design bounded by an experimental "bake-off," rather than forcing optimization to a specific frequency from the start.

The flight software components associated with the SSPB mission are as follows:

- The Satellite Bus (containing multiple systems/subsystems) software comes pre-integrated with the satellite bus system, which includes a user-programmable and extensible avionics/data system,
- The Software Defined Radio (SDR) Transceiver for the Satellite Bus, which forms the Communications System, comes with predefined wave form libraries and/or electronics slices to support desired frequencies as well as the necessary code for operational use,
- The H_20 Thruster - Propulsion System includes an Applications Programming Interface (API) for interfacing with the Guidance, Navigation, and Control (GN&C) System/Satellite Bus Avionics,
- The Data Capture & Analysis System - Data System Overlay includes an API for making the necessary connections to interface with all SSPB mission components,
- The baseline rectenna, while a source of data, is not anticipated to be programmable. However, certain rectenna enhancements may be implemented that could alter this assumption.
- Both the ISS and satellite bus transceivers are subject to the inclusion of software and in some cases hardware enhancements to increase end-to-end system performance.

In addition, XISP will contribute the tools for building:

- Near–real-time state model/control capability – This will permit the characterization, optimization, and codified compliance with operational rules of the radiant energy beaming testbed, the demonstration system, and the infrastructure deployment system.

- Radiant energy beaming control and safety interlock system – This system will make use of the XISP-Inc MOCA – (XISP Xlink near–real-time state model extended NASA ARC Mission Control Technologies OpenMCT software suite), and an IPv6 Delay/Disruption Tolerant Networking (DTN) enabled implementation of WAVElan SECurity using IPsec (WAVESEC) compatible with the Immortal Data Inc. Shipslog Data Capture and Analysis system.
- Other Software/Ancillary Utility Related Components – The ability to accommodate power, data, communications, navigation, and time multiplexing within radiant energy beams is not anticipated to be materially different from existing terrestrial and space multiplexing tasks. The ISS Space Communications and Navigation (SCaN) Test Bed has demonstrated the use of a library of Software Defined Radio waveforms on orbit. The addition of power and ancillary services waveforms in the library of a Software Defined Radio (SDR) is anticipated to be just another instance of a well-defined process.

Overall SSPB Operation

The overall ISS SSPB operation involves the following main elements:

1) Input Power Interface ➔ 3 to 6 Kw, JEM Exposed Facility Port
2) Secondary Conversion: DC Power to Microwave/Optical (~95% efficient depending on voltage multiplier ratio)
3) Transmit Aperture: Beam Forming Antenna/Optical Collimator (70%-97% efficient, circa 1992)
4) Transmission/Distribution/Control: Free Space Transmission (5%-95% efficient, circa 1992)
5) Receive Aperture: Beam Receiving Rectenna/Optical Collector
6) Tertiary Conversion: Microwave/Optical to DC Power (~95% efficient depending on voltage multiplier ratio)
7) Output Power ➔ TBD to Spacecraft Power System Bus
   Estimated end-to-end efficiency DC input power to DC output power to bus will be greater than 54%.

This will demonstrate SSPB by powering the CubeSat from the ISS-based, frequency-agnostic SDR transceiver, operating between the high end of the Ka band, through W band, and up to eyesafe optical as appropriate.

While use of one or more of the available Ka band (27 to 40 GHz) communications transmitters on ISS may be technically feasible, operations considerations associated with additional use of already burdened ISS mission critical systems are another compelling reason to advance to higher frequencies from the start by using the proposed ISS transceiver. Also, achievable power densities at a specified distance between transmitter and receiver are dramatically higher by increasing beam frequency, despite an anticipated fall off in efficiency. Even more striking is the almost-one-order-of-magnitude reduction in rectenna area required for moving from the Ka Band to the W Band.

Implementation Partner

XISP-Inc has selected NanoRacks, Inc. as the implementation partner for the SSPB mission based on their continuing expressions of interest in the XISP-Inc commercial mission set, their interest in and investment in expanding the available ISS infrastructure, and a proven history of supporting ISS mission deployments. In particular, the use of the NanoRacks, Inc. Kaber deployment interfaces, payload network interfaces, the JEM Kibo Airlock, and the forthcoming NanoRacks, Inc. commercial airlock are deemed of particular value. Overall, having an integration partner with a proven record of accomplishment of success, shared goals, and a willingness to collaborate/innovate as well as invest resources in XISP SSPB missions has made NanoRacks, Inc. a compelling choice.

Facilities and Other Resources

The ability of XISP-Inc to accomplish the SSPB mission is critically dependent on leveraging existing ground and space facilities and other resources to complete applicable preflight work, ground controls, and space operations. More specifically, two forms of testing are required to accomplish the mission objectives:

- Piecewise iterative testing of components (i.e., Satellite subsystems, ISS transmitter & apertures, Payload Rectenna, radiant energy beaming control and safety interlock system, Other Software/Ancillary Utility Related Components).
- Recursive integrated, mixed-mode end-to-end ground testing / verification & validation with increasing levels of fidelity (Form/Fit/Function Models ➔ Protoflight ➔ Flight Equipment) is required to accomplish the mission objectives.

SSPB Mission Consortium participants have been chosen in part because of the existing resources they can bring to the mission. It is anticipated that most piecewise iterative testing will be accomplished by the vendors supplying each component by leveraging their in-house testing databases, quality control processes, and facilities. Recursive integrated end-to-end ground testing to accomplish Verification & Validation will be accomplished using resources provided by other SSPB Mission Consortium participants. Examples include higher fidelity integrated testing (i.e., satellite bus, interfaced transmitter, apertures, rectenna, controls, and ancillary components) as well as Temperature/Vacuum, EMI/EMC, and GN&C/ACS testing, which require specialized facilities.

Ground-based Studies

Ground based studies will be used to converge the family of design solutions for the ISS transceiver and the CubeSat rectenna. In conjunction with the NASA ARC Mission Control Technologies Laboratory as well as other interested parties, the initial ground testbed work has a numbered of defined objectives:

- Define and implement/prototype a scalable parametric model for unbundled power systems for sustained free-flyer spacecraft operations extensible to infrastructure operations, propulsion, and/or surface operations.
- Exercise the parametric model to demonstrate:
  - An understanding of the unbundled power system trade space,
  - Any interactions between and with unbundled power system elements, both in terms of what is known and what is known to be unknown,
  - Unbundled power system element specifications, as well as
  - A characterization of all required interfaces.
- Inform and facilitate the technology development by supporting mixed mode simulation using a combination of existing equipment analogs, protoflight equipment, and flight hardware. This will allow simulations with increasing fidelity to both validate the parametric model for incorporation into a near real-time state model of the unbundled system and support the verification and validation of all SSPB mission required interfaces.
- Provide a means to infuse the best available transceiver and rectenna technology development enhancements from the SSPB Mission Consortium researchers into the SSPB mission systems engineering process

It is anticipated that as part of the SSPB mission verification & validation work, multiple ground-based walk throughs of the entire mission operations planned sequences, as well as degenerate failure cases, will be accomplished. Both the ground and flight experiments will make use of the XISP-Inc MOCA (Mission Control and Operations Application - a web-based application of the XISP Xlink near–real-time state model extended NASA ARC Mission Control Technologies OpenMCT software suite) and an IPv6 Delay/Disruption Tolerant Networking (DTN)-enabled implementation of WAVElan SECurity using IPsec (WAVESEC) compatible with the Immortal Data Inc. Shipslog Data Capture and Analysis system. Unless the WAVESEC link is established, authorized, and validated, outbound transmitter power will be inhibited to a minimum sensible level.

The SSPB flight readiness review has assessed all required flight elements as well as their constituent systems/subsystems and has found them to be within the stated TRL bounds of the mission.

2.3.2 Impact and Feasibility of Project Success

XISP-Inc will transition from what is de facto a startup company and grow from one employee to approximately 5 employees (technical + administrative), plus consultants and consortium participants to support Phase I of this mission, and will be poised to continue growing as mission execution moves forward and the ground work for creating the first space-based Electrical Power and Ancillary Services Utility is laid.
The planned investment tranches are:

- Phase 1 technology development will leverage the IRaD work and other assets of the SSPB consortium participants resulting in products that are useful for the SSPB mission and other space and terrestrial applications. Hence the initial customers are the SSPB consortium. It is anticipated that the combination of secondary market volume which reduces the unit costs of required SSPB elements as well as newly developed power and ancillary services beaming intellectual property will result in a positive balance sheet for XISP-Inc as well as make the Phase II Technology Demonstration a compelling investment for an evolving set of SSPB consortium participants as well as allow for XISP-Inc debt/equity financing.
- Phase II technology demonstration has two defined alternatives.
    - Alternative A assumes minimum Cygnus integration, the SSPB flight package will be a Cygnus secondary payload flown at a concessionary rate with the product being a proven ability to deliver power and ancillary services to the respective Cygnus core payload interfaces. If this alternative is taken it is anticipated that the XISP-Inc balance sheet will continue to improve in this Phase but XISP-Inc will have to continue to rely on a combination of secondary market volume and investment from an evolving set of SSPB consortium participants as well as XISP-Inc debt/equity financing to cover operational costs in this Phase. It is anticipated that the results of the Phase II mission will allow a compelling case to be made for the Phase III Technology Deployment investment by an evolving set of SSPB consortium participants as well as well as XISP-Inc debt/equity financing.
    - Alternative B assumes full Cygnus integration, the SSPB flight package will be Cygnus infrastructure which delivers power and ancillary services to respective Cygnus core payload interfaces. The resources provided would be paid for and used by the other Cygnus secondary payloads for which an ISS crew-tended co-orbiting lab with more stringent micro-gravity specifications and more flexible experiment protocols, and with product return capability would be of value. If this alternative is taken it is anticipated that the XISP-Inc balance sheet will continue to improve in this Phase and net income sufficient to cover the Phase I and Phase II financing with some profit will be achieved. It is anticipated that the results of the Phase II mission will allow a compelling case to be made for the Phase III Technology Deployment investment by an evolving set of SSPB consortium participants as well as well as XISP-Inc debt/equity financing.
- Phase III technology deployment assumes the value of the resources provided for and used by the other Cygnus secondary payloads for which an ISS crew-tended co-orbiting lab with more stringent micro-gravity specifications and more flexible experiment protocols, and with product return capability would cover the cost of the required equipment, operations, and allow for a compelling profit. This could be achieved by XISP-Inc leasing the Cygnus module after ISS delivery for some number of cycles from Northrup Grumman Innovative Systems (NGIS) and selling the payload space, or an innovative brokerage arrangement with NGIS achieving the same. It is anticipated that the results of the Phase III mission will allow a compelling case to be made for follow-on technology development, demonstration, and deployment work driven by investment by an evolving set of SSPB consortium participants as well as well as substantial infrastructure debt/equity financing consistent with terrestrial power generation and transmission capacity building including the provision of ancillary services.

- Follow-on work is the evolution into an electrical power and ancillary services utility for Cislunar space, the Lunar Power & Light Company™ (LP&L) offering a range of value-added Space and Earth services.

Profits from the work on the SSPB mission will be leveraged to develop other missions in the XISP-Inc commercial mission set. To date, there is no market per se for electrical power utilities in space; every spacecraft has to bring their own. For current spacecraft, except for the ISS, there is no recovery capability from infant mortality, degradation, or unanticipated failures. With the advent of satellite servicing capabilities in the years to come, some additional options will become available. The ability to support a progression of electrical power utility delivery ranging from Emergency ➔ Servicing ➔ Augment ➔ Backup ➔ Primary is projected to lead to incremental revenue growth.

As space development activities expand, driven by new market opportunities and lowering launch costs, the addressable markets for power will become more tractable. It is anticipated that the opening of each addressable market will result in a strong step function of growth in the space electrical utility market. As noted previously, the largest customers for power in Cislunar space are the Geosynchronous Communications Satellites (~443 active), with electrical energy demands ranging from ~2 to ~20 kW. The satellite communication market is splitting into two: a new market for large constellations of small satellites to serve some combination of acceptance-level customers (Quality of Service [QoS] provided is what can be delivered) and special purpose customers that will now be able to afford dedicated satellite communications, and a maturing QoS-driven market commodity market. The latter is evolving to larger and increasingly immortal platforms with plug-in/plug-out technology and rapidly increasing electrical energy demands. The ability to provide power and ancillary services to address both of these markets as a progression from Emergency ➔ Servicing ➔ Augment ➔ Backup ➔ Primary will increase in value over time, and will prove to be mission enhancing if not mission enabling as new systems are designed to use the evolving capabilities. The early implementation of a power beaming demonstration on the ISS coordinated by XISP-Inc could enhance and enable the demonstration of other power beaming designs and hasten the implementation of commercial space station augments and extensions to service this and other Cislunar markets.

The situation with respect to ancillary services has some available utilities but they tend to be limited, fragmented, and not designed for interoperability. The inclusion of ancillary services utilities will broaden and accelerate market growth.

The socioeconomic benefit of this work includes reinforcing the United States leadership in the global high-tech marketplace, as well as providing opportunities for international cooperation and collaboration. In practical terms, the success of the SSPB mission will impact the trade space for meeting the electrical power and ancillary service requirements for a variety of emerging addressable Cislunar markets, starting with the ISS LEO co-orbiting market and proceeding to other markets as operational systems can be fielded. Numerous entities, including government (e.g., NASA, DoD, and DHS) and commercial (e.g., Northrop Grumman Innovation Systems (formerly OrbitalATK), ViaSat, United Launch Alliance, Made In Space, Blue Origin, OrbitFab), have expressed interest in being customers for beamed power and/or ancillary services. XISP-Inc is part of the ULA-sponsored Cislunar Marketplace development effort involving over 150 entities, and intends to evolve to serve the anticipated $3 to $8 billion/year market for Geo Comsat power within 10 years and other addressable markets from the Karman Line (100 km) up through to the surface of the Moon.

3.2 Innovation: The shift from mandatory self-sufficiency for the lifecycle of a spacecraft to the availability of an evolving set of utilities and servicing options is a fundamental and inevitable economic/design paradigm shift that the SSPB mission is designed to exploit. The core innovation/advancement is that power and ancillary services beaming allows for the more parsimonious use of resources and ephemeralization "the doing of more with less," as well as the determination as to whether there are economies of scale to be found with power generation and distribution in space. The results of this mission will not only be enhancing for other missions, they will be enabling. This will allow for a wider range of opportunities for further space exploration and development to come to fruition. XISP-Inc not only plans on publishing the results of the SSPB mission, but the generation of papers, presentations, and follow-on proposals are an integral part of the mission. The results of the mission are the most effective marketing for commercial follow through. The results will entail a well-curated characterization of what is public domain, what is owned intellectual property, and how licenses can be readily obtained supported by agreement of the SSPB Mission Consortium. The SSPB mission development work to date has already established the proposed principal investigator as a leading researcher in the field of space solar power/radiant energy beaming application development.

3.3 Benefit to Humankind and Social Impact: The SSPB mission will engage multiple generations of engineers to develop new capabilities, infrastructure, and human capital that will help prepare our nation and world for the challenges of the 21st century and beyond. The near-term benefit of this mission is that it increases the available resources of the ISS National Lab by facilitating and supporting the operation of crew-tended co-orbiting free-flying systems. In the mid-term, the Cislunar electrical and allied utilities services will prove valuable in supporting the growing utility needs of the next generation of Earth- and space-facing applications, satellites, platforms, and facilities. In the long term, Space Solar Power technology may prove instrumental in meeting both the United States' and the world's baseload electrical energy demand in a cost-effective, safe, and PB environmentally benign manner, as well as saving lives by rapidly delivering power to disaster areas and other mission-critical environments.

The SSPB mission has benefited from an extended mission development process that has included years of peer review at multiple levels and vetting by government (NASA, DoD, NOAA, DHS, etc.) and commercial interests (Raytheon, Northrop Grumman, Made In Space, ULA, etc.). The proposed work is deemed as applied engineering, not new physics. Accordingly, the preponderance of evidence suggests that it is not only feasible but a tractable mission that results in practical applications to other missions. The practicality and efficiency of the end-to-end systems deployed from this effort will drive their subsequent inclusion in future infrastructure/spacecraft designs.

3.4 Feasibility: XISP-Inc has already provided substantial cash and In-kind funding (in excess of $1 million), and all SSPB Mission Consortium members have agreed to contribute at least a minimum Industry Contribution of 25% (cash and In-kind). Multiple members of the SSPB Mission Consortium are capable of contributing a meaningful amount of SSPB project funding and Intellectual Property, and all compensated consortium members will meet or exceed the minimum industry contribution required. Furthermore, assuming success of the project, multiple members of the SSPB Mission Consortium have the resources and are committed in principle to help commercialize the results. It is anticipated that given an allocation of the ISS National Lab resources, commercial cargo space, integration verification & validation support, and a modest amount of mission development funding, XISP-Inc will be able to raise the remaining funds required through a combination of grant, debt, and/or equity financing. XISP-Inc has received a written acknowledgment from AA for HEOMD that NASA is willing to consider direct funding to add additional milestones and/or accelerate milestones if conditions are met.

The research methodology and operational approach has been developed on an iterative and recursive basis through over 5 years of technical peer review of presentations, papers, and proposals in close cooperation/collaboration with internationally recognized experts in the field, including the proposed Principal Investigator. NASA HEOMD has stated through proposal evaluation that the proposed team has the necessary and appropriate experience and expertise. The research plan is robust enough to sustain the interest and desire to participate in the SSPB Mission Consortium. The flight hardware options have been vetted through multiple means and processes. In addition, provisions have been made to ensure that the mission has a baseline path for successful execution and sufficient optional overlays (e.g., multiple technologies, multiple vendors, scalable tests, balanced interests/objectives/agendas) to mitigate all cost, schedule, and technical risks identified to date. The required hardware and software leverages existing COTS products and past and current IR&D work.

In Phase 2, the Northrop Grumman commitment to a Cygnus demonstration becomes the first customer served, accommodating their requirements for fault-tolerant power and ancillary services for both co-orbiting free-flying spacecraft and payload operations. The key business driver is that there are economies of scale to be found in the generation and transmission of power and ancillary services in space for customer applications. We anticipate that the SSPB TD^3 mission will lay the technological foundation for our Cislunar electrical power and ancillary services entity, the Lunar Power & Light Company™ (LP&L). LP&L intends to serve the anticipated $3 to $8 billion/year market for Geo Comsat power within 10 years and other addressable markets from the Karman Line (100 km) up through to the surface of the Moon. XISP-Inc is part of the ULA-sponsored Cislunar Marketplace development effort, which involves over 150 entities. It is anticipated that the combination of the revenue from the power and ancillary services provided to the ISS co-orbiting/LEO customers and the value of the perceived and/or real cost, schedule, and technical risks retired by the TD^3 mission will realize a large-enough return to secure the follow-on investment required to build out the Lunar Power & Light Company™.

XISP-Inc received input from NASA JSC Code OZ regarding our January 20, 2017 submittal on the RESEARCH OPPORTUNITIES FOR ISS UTILIZATION NASA Research Announcement: NNJ13ZBG001N Soliciting Proposals for Exploration Technology Demonstration and National Lab Utilization Enhancements. This input stated as follows: "NASA has determined that Space-to-space power beaming is of interest to NASA and has the potential to affect a wide range of missions and is a potential key element of space infrastructure for the future. Overall, the proposal [proposed mission] is relevant to NASA's exploration goals and reflects the involvement of a team with appropriate experience." The Department of Defense (DoD), National Oceanic and Atmospheric Administration (NOAA), and Department of Homeland Security (DHS) all operate (or would like to operate) satellite systems capable of using power and ancillary services beaming to meet specific requirements for performance, availability, and security.

There is an open market for degrading legacy systems in the near term, an evolving market for new enhanced satellites in the mid-term (~2 to ~5 years), and an essential element of "immortal" serviced platform systems that will be designed to accommodate multiple generations of payloads in the long term (~5 to ~10 years). Any enhanced electrical power and ancillary services made available on an in situ and/or beamed basis to customers will be reflected directly as an increased ROI even after accounting for the recurring costs. Any electrical power and allied utility services made available would prove to be mission enhancing if not mission enabling, and has the potential for creating a reoccurring revenue stream.

XISP-Inc anticipates a market for ancillary services (i.e., communications, data, and navigation/time) and strategies for achieving an Interoperable Network Communication Architecture (INCA) as well as the Quality of Service (QoS) requirements (i.e., performance, availability, and security). Frequency-agnostic, (e.g., Software Defined Radios, electro/optical converged electronics, and selectable apertures) pervasively networked communications and data systems with provisions for Delay and Disturbance Tolerant Networking (DTN), including store and forward capacity, and QoS-based routing will likely be essential.

While the immediate environmental impact of the SSPB mission will be negligible aside from some additional operational rules, the value proposition of Space Solar Power technology for Earth-facing applications, on-orbit operations, and space-facing applications holds great promise. More specifically, applications of power beaming technology for orbital debris mitigation and for the potential for large-scale energy transfer are two areas that could have a dramatically positive environmental impact.

Proposal Section IV: STEM and Educational Outreach Component

XISP-Inc intends to provide opportunities for constructive engagement of undergraduate and graduate students in academic-schedule–compatible capacity-building research and operations work directly supporting space TD^3 missions. Opportunities are being crafted with a variety of universities to support the integration of enhanced flight test article components and innovative testbed research tracks, as well as experiment operations via virtualized operations centers. In addition, as a rapidly advancing TD^3 mission, there are multiple opportunities for aspirational and technical STEM teaching moments based on the technical details of the mission as well as the potential applications that can be tailored to K-12 students. XISP-Inc maintains involvement with multiple STEM outreach and engagement activities involving non-profit and university partners including, but not limited to, University of Maryland Space Systems Lab Design Review Participation.

XISP-Inc appreciates the importance of public information generation and dissemination at all levels, including both a vigorous peer review and STEM education component, as an integral part of the proposed mission. XISP-Inc has developed and maintains relationships with a wide range of space advocacy organizations including the National Space Society & affiliated organizations, Students for the Exploration and Development of Space (SEDS), and the Space Foundation.

XISP-Inc will implement a state-of-the-art Colab website for the SSPB mission, which will enable virtual cooperation, collaboration, and workflow between participants located around the country including the wider STEM community. XISP-Inc will maintain a public website section of this site providing an ongoing summary of the SSPB mission status and all publicly released SSPB mission work products.

Proposal Section V: Budget and Schedule

The total estimated time to complete the SSPB TD^3 mission as scoped is thirty-six (36) months. The runout budget estimate (both cash and In-kind contributions) for the SSPB TD^3 mission is less than $13 million. The SSPB mission budget is outlined in detail in Table 2 – XISP-Inc SSPB Mission Preliminary Total Project Cost Funds. The total funds are to be raised and contributed by members of the Consortium. Current key commercial members of the consortium include: XISP-Inc, Raytheon, Orbital ATK, Made In Space, Satellite Bus & System Vendors (bid out), Immortal Data, Deep Space Industries, NanoRacks, and Tethers Unlimited. XISP-Inc requires the SSPB mission to have recognizable standing (i.e., CASIS approval) in order to complete the commercial capital raise required to execute the SSPB mission. The balance of required funds will have to be raised from a combination of grants, NASA Space Act Agreement milestone achievement contracts, Department of Defense CRADA contracts, equity financing, and debt financing.

The total CASIS Implementation Partner preliminary budget assumes Implementation Partner assistance with one (1) 6U CubeSat flight test article (~14 kg) installed in a mission-appropriate deployment canister. The flight test article shall use H2O-based thrusters. The flight test article shall be shipped to station as soft pack pressurized cargo on a commercial cargo flight and one (1) JEM Exposed Facility payload carrier (less than 500 kg) shipped to the station as unpressurized cargo on a commercial cargo flight. The CASIS Implementation Partner will be an integral part of the Mission Development and Technology Development Phases of the SSPB mission. The Implementation Partner costs associated with NanoRacks are XISP-Inc estimates based on conversations with NanoRacks and other vendors. It anticipated that the majority of the Implementation Partner Northrop Grumman Cygnus costs will be In-kind.

The top level milestone schedule is shown in Table 3 -- SSPB Phase I, II, and III Milestone Schedule. The mission budget assumes a minimum level of NASA direct funding each year as a placeholder for potential direct participation by NASA by either adding additional milestones and/or accelerating milestones along with the commensurate funding for accomplishing the same.

5.1 Budget (Cost Proposal)

Funds are being requested from CASIS for XISP-Inc to complete the required SSPB mission development, a portion of the funding for XISP-Inc required to execute the SSPB mission, and the costs associated with CASIS Integration Partner support. The funds requested for XISP-Inc will be used to cover allowable costs including the Salary/Fringe and approved mission related travel for the Principal Investigator. XISP-Inc does not have a current indirect rate agreement approved by a federal agency. However, historic Barnhard Associates, LLC and matching XISP-Inc indirect rates that are part of the fully burdened rates that are customarily charged government agencies and commercial clients have been used to provide a complete buildup of rates, which is available on request. The CASIS budget template has been completed and provided.

5.2 Budget Related Attachments (CASIS-Provided Templates)

The required budget-related attachments have been completed using the CASIS-provided templates.

Table 2 – XISP-Inc SSPB Mission Preliminary Total Project Cost

	Year 1-2: ~16 Months 9/2018 to 1/2020		
	Hours, indirect cost base, or fee/profit base, as applicable	**Rates**	**Costs**
Labor Categories: [1]			
Gary Barnhard, Principal Investigator, Mission Technical Director (35+ years and specialized experience)	1,985	$74.82	$ 148,493
Mission Deputy Technical Director, Space Systems Engineer (15+ years and specialized experience)	0	$62.35	$ -
Engineer III - Senior Systems Engineer (20+ years or specialist)	2443	$62.35	$ 152,300
Engineer II - Systems Engineer (10-20 Years or equivalent)	2443	$49.88	$ 121,840
Engineer I - Discipline Engineer (1-10 Years or equivlent)	2443	$37.41	$ 91,380
Total Direct Labor Cost [1]	9313	$55.20	$ 514,013
Fringe Benefits [2]		28.08%	$ 144,323
Labor Overhead [2]		29.37%	$ 150,979
Loaded Labor			$ 809,316
Travel [3]	$ 100,000	1.33	$ 133,333
Material, Equip., and ODCs [4]		1	$1,420,000
● *Satellite Bus w/enhancements & Integration Support*	1,000,000	Blue Canyon Tech	
● *SDR Transceiver - Communications System*	195,000	Tethers Unlimited	
● *H_20 Thruster - Propulsion System*	165,000	Deep Space Industries	
● *Data Capture & Analysis System - Data System Overlay*	60,000	Immortal Data	
Subcontract(s) [5]			$ 2,400,000
● ISS Transceiver, Baseline Rectenna & Support	2,000,000	Raytheon	
● Rectenna & Tx/Rx Aperture Printing	25,000	Made In Space	
● Transceiver Enhancement	75,000	TBD Collaborators	
● Rectenna Enhancement	75,000	TBD Collaborators	
● Optical Enhancement	75,000	TBD Collaborators	
● Integration, Testing & Operations Support	150,000	UMCP SSL	
Consultant(s) [6]			$ 283,963
● Consultant II - Mission Subject Matter Specialist		$150.00	
● Consultant I - Mission Discipline Analyst		$93.75	
Cost Reserve		10.00%	$ 560,828
Subtotal			$ 5,607,440
G&A [2]		10.00%	$ 560,744
Total Offeror Cost (U)			$ 6,168,184
Offeror Profit (V)		10.00%	$ 616,818
CASIS Integration Partner		NanoRacks, Inc.	$ 125,000
NASA Civil Servant/Other Government Labs (W) [7]			$ 26,667
● Naval Research Lab - Temp/Vacuum/EMI/EMC & Multi-body Testing, Collaboration		$ 26,667	
● Air Force Research Lab/SpRCO - Ground testing, Collaboration (invited)		TBD	
● NASA GSFC - Ground testing, Collaboration (invited)		TBD	
Estimated Total Project Cost (X = U + V + W)			**$ 6,936,669**
Minimum Industry Contribution (Y = X - V) x (at least 25%)	X	**25.00%**	**$ 1,579,963**
Estimated Additional Cash and In-kind Amount to Be Raised (Z = U + V - Y)			**$ 5,205,040**

NOTES:

(1) DIRECT LABOR: The total quantity and mix of labor was based on similarilty to the requirements of other analogous space and terrestrial projects , the likely scale of available funding, the Direct Labor Cost, and the Statement of Work/Work Breakdown Structure.

(2) INDIRECT COSTS: Since XISP-Inc is essentially a startup company financed by Barnhard Associates, LLC the indirect rates were estimated by equating the XISP-Inc indirect rates to Barnhard Associates, LLC indirect rates (the firms are collocated). Transition accounting will be addressed in the effective business relationship inversion between Barnhard Associates. LLC and XISP-Inc on contract award.

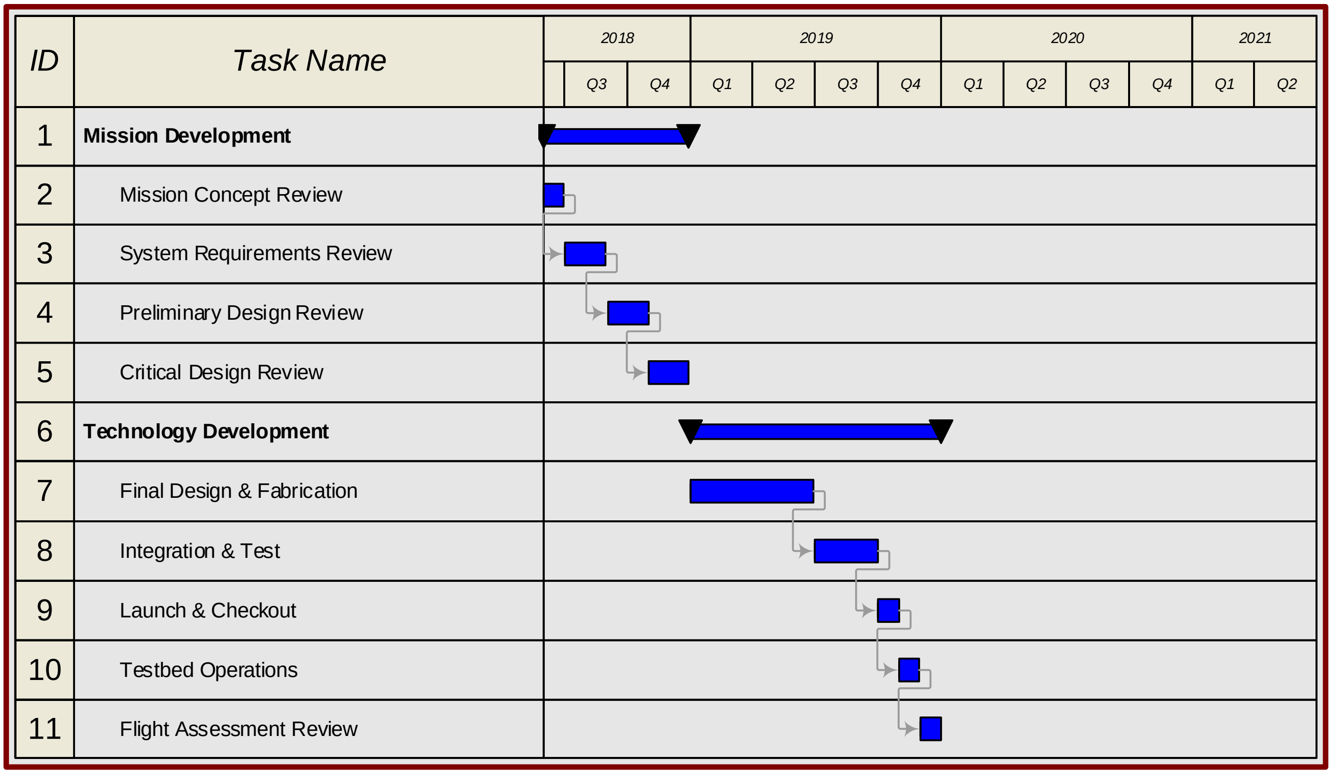
(3) TRAVEL: Estimated travel budget developed using the Scheduled Travel for review participation, current GSA per Diem rates for lodging, meals, and incidentals, estimated transportation expenses, and estimated number of participants.

(4) OTHER DIRECT COSTS (ODCs): In order to secure the most advantageous pricing an allocation of costs based on the aggregation of individual vendor estimates has been provided. These estimates must be affirmed by definitized quotes as part of the mission development process.

(5) SUBCONTRACT(s): In order to secure the most advantageous pricing an allocation of costs based on the aggregation of individual vendor estimates has been provided. These estimates must be affirmed by definitized quotes as part of the mission development process.

(6) CONSULTANT(s): In order to secure the most advantageous pricing a pool of potential consultants was listed. Some transition from Constant to Employee status is anticipated.

(7) NASA CIVIL SERVANT/Other Government Lab COSTS: The Naval Research Lab estimated co-payment for access to resources is provided.The costs associated with the proposed AFRL and NASA GSFC work remains to be negotiated.



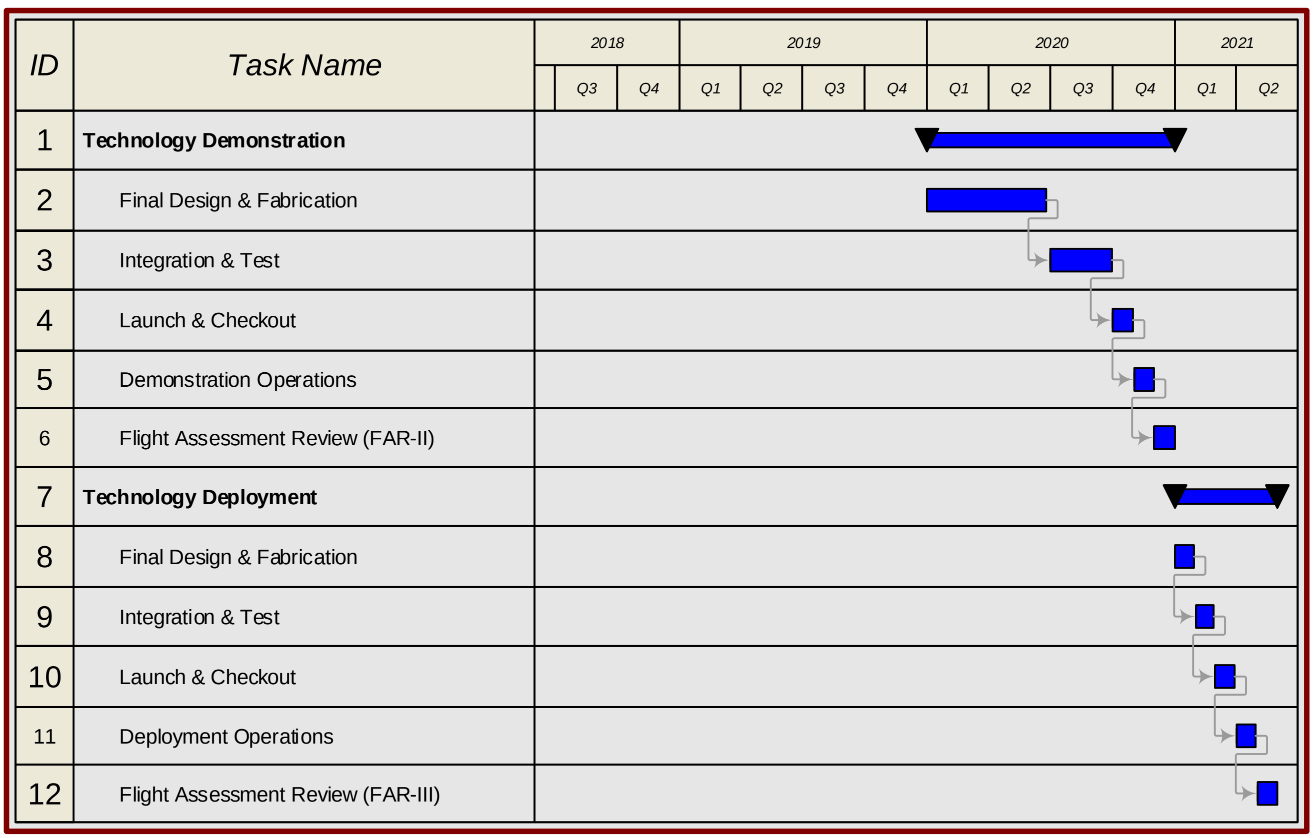


Table 3 -- SSPB Phase I, II, and III Milestone Schedule

Proposal Section VI: Biographical Sketch

6.1 Principal Investigator Biographical Sketch

The proposed Principal Investigator, Gary Pearce Barnhard, is a computer, robotic, and space systems engineer with over 35 years of professional systems engineering experience. He has taken a leading role as both an advocate and researcher in space solar power technology on national and international levels. Mr. Barnhard, a self-described synergistic technological philanthropist, entrepreneur, and serial venture capitalist now serving as the President & CEO of Xtraordinary Innovative Space Partnerships, Inc. (XISP- Inc) a start-up company focused on International Space Station technology development work as well as the owner of Barnhard Associates, LLC, a systems engineering consulting firm and Internet Service Provider (Xisp.net) based in Cabin John, Maryland. He received a Bachelor of Science in Engineering from the University of Maryland College Park in 1982 combining Aerospace Engineering, Materials Science, with graduate work in science policy, solar physics, and artificial intelligence/knowledge based systems.

He served as a Space Systems Engineer and Information Systems Architect for EER Systems, and as a Senior Space Systems Engineer on the Grumman Space Station Systems Engineering and Integration Contract (SSEIC) responsible for advanced automation and robotic systems support. He was the Executive Secretary of the Space Station Freedom Program Robotics Working Group and received a NASA Group Achievement Award for the Robotic Systems Integration Standards Interface Design Review Team, as well as an Outstanding Support Award from the Canadian Space Agency Space Station Freedom Program Liaison Office. He is an Associate Fellow of the AIAA. He is a member of the AIAA Space Colonization Technical Committee and the AIAA Space Automation and Robotics Technical Committee. He is a life member of the National Space Society (NSS) serving the society in many capacities including Chief Executive Officer, Executive Director, and member of the Board of Directors. He has received multiple awards for this work including the NSS Pioneering Space Award (2004); NSS Award for Excellence in (2005) & (2008). He was the Executive Director and cofounder of 1000+ member Space Interest Group MSFA/MASC (1977-1982) (L5 Society affiliate). Other space advocacy involvement includes: Space Development Foundation Founder/President/CEO, Space Studies Institute (SSI) Senior Associate, Planetary Society member, American Astronautical Society (AAS) member, Space Frontier Foundation (SFF) Advocate, and Students for the Exploration and Development of Space (SEDS) Alumni.

In particular, his previous work on the Space Station Engineering and Integration Contract (SSEIC) is highly relevant included serving as the Automation & Robotics Lead Engineer for the Structures, Mechanisms & Robotics Branch of SSEIC. He was the SSEIC recognized expert in robotic, space, and computer systems analysis/systems engineering responsible for evaluating all robotics (and most advanced automation) related Space Station Control Board (SSCB) Engineering Change Requests, writing the SSEIC opinion, jurying all SSCB opinions, and presenting the integrated decision package to the SSCB. Key activities included: development, negotiation & documentation of the Robotic Systems Integration Standards (RSIS), Volume I: Robotic Accommodation Requirements, and Volume II: Robotic Interface Standards; analysis of collision detection & avoidance methods; development & assessment of fault-tolerant system architectures; technical risk assessment/mitigation; and Space Station Robotics Working Group support as SSEIC Lead & Executive Secretary. These efforts required extensive negotiation/collaboration with NASA centers, industry, international partners, and academia. He was responsible for definition, management, verifiability, and flow down of Program & System level requirements for advanced automation and robotics for the Space Station Program, SSEIC technical Lead and coauthor of the Systems Requirements documents for the Mobile Servicing Centre (MSC) and the Special Purpose Dexterous Manipulator (SPDM). He led the team responsible, and received a NASA Group Achievement Award, for the development of the Robotic Systems Integration Standards (RSIS) Volumes I (Accommodation Requirements) & Volume II (Interface Standards), and the Space Station External Utility Port Standardization project. He was a direct participant in requirements/interface negotiation, design assessment/review, and interdisciplinary problem resolution for all Space Station robotic systems/elements and Space Station Program level reviews.

Other prior work that is relevant includes: participant in the development and analysis of the Space Station User Information System Requirements, and the Space Station Data Systems Requirements, architect and lead engineer for the development of a master engineering database system and modeling tools for the support of multi-discipline systems engineering design analysis, concept development, and problem resolution. He also served as part of the Space Station Mission Requirements Working Group Technology Development Missions Panel responsible for the NASA GSFC Technology Development Missions, co-authored all NASA GSFC Space Station Mission Requirements Working Group Data Base submissions and supported the editing and review of all submissions.

Mr. Barnhard's technical work with XISP-Inc includes defining and executing commercial TD^3 missions that leverage the extraordinary resources of the International Space Station along with other government, commercial, educational, and non-profit assets. XISP-Inc's objective is to form extraordinary innovative space public/private partnerships to further the development of innovative technology and applications, useful for space exploration and development as well as terrestrial markets. These efforts can serve to bridge the technology development "valley of death" as well as substantially mitigate (perceived and actual) cost, schedule, and technical risk associated with the short-, mid-, and long-term applications of the technology. The current XISP-Inc commercial mission set includes: Space-to-Space Power Beaming (SSPB), Management Operations Control Architecture/Applications (MOCA), Interoperating Network Communications Architecture (INCA), Halfway To Anywhere (HTA), and the Alpha CubeSat (ACS). Further details on these missions and other nascent ones are available at http://www.xisp-inc.com.

Mr. Barnhard's technical work with Barnhard Associates, LLC (BALLC) includes serving as architect/network engineer/consultant/licensed reseller providing computer systems engineering, consulting, and integration services for business, government, academic, and individual clients. Scope of work includes: custom and semi-custom solution development and fielding including all necessary hardware, software, integration, contracting, installation, testing, and support services. Work has included extensive involvement from initial requirements analysis/development through fielded operations and support in a wide variety of environments from embedded computing to mainframe systems.

Since 2005, the proposed Principal Investigator Gary Barnhard has written over 55 related technical papers and/or presentations germane to the proposed SSPB mission to a wide range of professional fora related to space solar power, ancillary services (i.e., communications, data, and navigation/time) and the evolution of proposed TD^3 missions. Papers/presentations are planned for ISDC 2018, as well as at ISS R&D Conference 2018*, AIAA Space 2018, IAC 2018, and WiSEE 2018*
(* pending abstract acceptance).

Professional References

Professional references for the Principal Investigator are available from the following points of contact on request:

- Dr. David Akin, University of Maryland Space Systems Lab – dakin@ssl.umd.edu
- Dr. Paul Jaffe, Naval Research Lab – paul.jaffe@nrl.navy.mil
- John Mankins, Mankins Space Systems, Inc. – john_c_mankins@yahoo.com
- Dr. Seth Potter, Independent Consultant – sethpotter3@gmail.com
- Jim Schier, NASA Headquarters, HEOMD SCaN – james.schier-1@nasa.gov
- Dr. Paul Werbos, Independent Consultant – werbos@ieee.org

6.2 XISP-Inc SSPB Mission Consortium

Descriptive paragraphs, biographical sketches, resumes, and publications lists are available for all participating members of the XISP-Inc SSPB Mission Consortium. Since the compendium of the same would be quite voluminous the various entities are included in the following lists:

Commercial Entities*

- XISP-Inc (staff, consultants, and other supporting organizations) – Mission Development, Financing, Management, Systems Engineering, Integration, Verification & Validation, Operations, & Marketing
- Raytheon, Inc. (Avram Bar Cohen, James McSpadden, et al.) – ISS Transceiver, Rectenna(s), Ground Test
- Northrop Grumman Innovation Systems (formerly OrbitalATK) (Bob Richards, Derek Hodgins, et al.) – Cygnus Secondary Payload and related applications, GN&C Validation
- Immortal Data, Inc. (Dale Amon, et al.) – Data Capture & Analysis, Mgmt. Ops Control Applications
- Made In Space, Inc. (Jason Dunn, et al.) – 3D Rectenna & Rx/Tx Aperture Printing
- Blue Canyon Technologies, Inc. (George Stafford, et al.) – Satellite Bus, Avionics
- Deep Space Industries, Inc. (Gran Bonin, et al.) – H_2O Thruster
- Tethers Unlimited, Inc. (Rob Hoyt, et al.) – CubeSat Transceiver
- AIRBUS DS, Inc. (Amy Hauser, et al.) – Columbus Bartolomeo Exposed Facility Accommodations
- Oceaneering – Bartolomeo and JEM Exposed Facility Accommodations and EVR support

*additional commercial entities are involved in the SSPB consortium but do not currently have an assigned role other than potential collaborator and/or customer.

Consultants*

- Beam Forming & Space Systems Engineering (Seth Potter), Independent Researcher
- Commercial Mission Development & Economics (Brad Blair), Independent Researcher
- Business Development & Space Systems Engineering (Daniel Faber), Independent Researcher
- Cooperative Agreements (Joseph Rauscher), Spacefaring Services
- Space Systems Engineering (David Cheuvront), Independent Researcher
- Program Implementation & Space Systems Engineering (Ken Ford), Independent Researcher
- Space Solar Power & Technology Development (John Mankins), Artemis Innovations, Inc.
- Energy/Physics Modeling & Technology Development (Paul Werbos), Independent Researcher
- Power Beaming & Technology Development (Richard Dickinson), Off Earth WPT
- Systems Integration (Michael Doty), Independent Researcher
- Communications & Data Systems Engineering (Aaron Harper), Independent Researcher
- RF Systems Testing (Tim Cash), Power Correction Systems, Inc.
- Optical Systems Testing (Tom Nugent), Powerlight Technologies
- Orbital Dynamics (Ed Belbruno), Independent Researcher
- Orbital Dynamics (Christopher Cassell), Alternate Independent Researcher
- Space Systems Engineering (Eric Dahlstrom), Independent Researcher
- RF/Power systems engineering, test, verification & validation (Brahm Segal), Power Correction Systems, Inc.
- Systems Engineering & Interface Development (Greg Allison), Independent Researcher
- International Relations (Alfred Anzaldúa), Independent Researcher
- Systems Engineering & Logistics (Anita Gale), Independent Researcher
- Systems Engineering, Space Policy & Economics (Jeff Greason), Independent Researcher
- Political Capital & Space Policy Development (James Muncy), Polispace, Inc.
- Systems Engineering & Beyond LEO Applications (Dennis Wingo)

*All consultants will become direct employees of XISP-Inc, XISP-Inc contract staff, or will specify an affiliation once the appropriate paper work is in place. Additional consultants have expressed interest in working with XISP-Inc but have not yet become directly involved in XISP-Inc proposal activities.

Government Entities

- Naval Research Laboratory (Paul Jaffe, et al.) – EMI/EMC, Thermal/Vacuum, and Multi-body testing
- NASA HEOMD*
    - AESD – Division Chief & Deputy (Jason Crusan, et al.) – Potential Customer & Collaborator
    - SCaN – Cislunar Communications & Navigation Architect (Jim Schier, et al.) – Potential Customer & Collaborator

  * HEOMD Associate Administrator (William H. Gerstenmaier) has requested that this completed proposal along with CASIS affirmation of intent to proceed be forwarded to his office for consideration of secondary NASA direct investment.
- DHS Customs and Border Protection (CBP) ** (Wolf Tombee, et al.) – Potential Customer & Collaborator

  ** The SSPB Flight Test Article, an instance of Alpha Cube Sat, could also part of a small sat constellation purchase or a fee for service arrangement.
- Space Rapid Capabilities Office (SpRCO)*** has been invited to participate in any capacity of interest to them.

  *** FY 2019 DoD Appropriations bill has allocated $283 million for space solar power capacity development.

Non-Profit Entities

- CASIS (Etop Esen, et al.)
- National Space Society (Michael Snyder, et al.)
- SPACE Canada (George Dietrich, Kieran Carroll, et al.)
- Space Development Foundation (David Dunlop, et al.)

Universities

- University of Maryland Space Systems Lab (David Akin) – Collaborator
- University of North Dakota Space Systems Lab (Sima Noghanian) – Collaborator
- University of New Mexico COSMIAC (Christos Christodoulou, et al.) – Collaborator
- St. Louis University (Michael Swartwout) – Collaborator
- Michigan Technical University, (Reza Zekavat) – Collaborator
- California Institute of Technology, (Michael Kelzenberg, et al.) – Collaborator

  * Other universities have expressed interest but as of yet have not provided a written declaration of the same.

International Space Agencies

- Japanese Exploration Agency (JAXA) – Potential Collaborator awaiting NASA/CASIS guidance
- Canadian Space Agency (CSA) – Potential Collaborator awaiting NASA/CASIS guidance
- European Space Agency (ESA) – Potential Collaborator awaiting NASA/CASIS guidance

Proposal Section VII: References

7.1 References

1. Brown, William C. Life Fellow, IEEE, and Eves, E. Eugene, “Beamed Microwave Power Transmission and its Application to Space”, IEEE Transactions On Microwave Theory and Techniques, Vol. 40, No. 6. June 1992
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3. McSpadden, J.O., Brown, A.M., Chang, K., Kaya, N., “A Receiving Rectifying Antenna for the International Space Year - Microwave Energy Transmission in Space (ISY-METS) Rocket Experiment”, IEEE AES Systems Magazine, November 1994
4. McSpadden, J.O., Change, K., Duke, M., Little, F., “Study of ISS Free-Flyer Power Beaming”, Proceedings SPS ’97 Conference, Montreal, Canada August 24, 1997
5. McSpadden, J.O., Mankins, J.C., “Space Solar Power Programs and Microwave Wireless Power Transmission Technology”, IEEE Microwave Magazine, December 2002
6. Jaffe, P.; Hodkin, J.; Harrington, F., "Development of a sandwich module prototype for Space Solar Power," Aerospace Conference, 2012 IEEE , vol., no., pp.1,9, 3-10 March 2012 doi: 10.1109/AERO.2012.6187077
7. Barnhard, G.P., “Is There a Business Case for Space Based Solar Power for Terrestrial Applications?”, Advanced Technology Working Group Meeting, NASA ARC December 9, 2008 -- Presentation, debate with Dr. Pete Worden, and ATWG Workshop Facilitator
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9. Barnhard, G.P., “Turning good ideas into gold - blazing a trail through the technology development valley of death” – International Space Development Conference (ISDC) 2012 Washington, DC -- Presentation May 26, 2012
10. Barnhard, G.P., presentation – “Suspending Disbelief - Unbundling Space Power Systems to foster applications of Space-to-Space Power Beaming”, International Space Development Conference (ISDC) 2013, San Diego, CA May 25, 2013
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12. Barnhard, G.P., “Unbundling Space Solar Power Systems“ Future In Space Operations (FISO) Colloquia – Presentation October 30, 2013
13. Barnhard, G.P., “Suspending Disbelief -- Unbundling Space Power Systems to foster applications of Space-to-Space Power Beaming”, IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) Space Based Solar Power Workshop, Baltimore, MD – Presentation November 8, 2013
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21. Barnhard, G.P., “Unbundling Space Solar Power Systems”, 4th Annual ISS R&D Boston, MA – Poster Session July 2015
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27. Barnhard, G.P.; Faber, D.; “Space-to-Space Power Beaming - A Commercial Mission to Unbundle Space Power Systems to Foster Space Applications", IAC 2016 Guadalajara, Mexico -- presentation and paper
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29. Barnhard, G.P.;“ISS Space-to-Space Power Beaming TD^3 Mission” - International Space Development Conference (ISDC) 2017, Space Solar Power Symposium, St. Louis, MO – Presentation May 25, 2017.
30. Barnhard, G.P.; Blair, Brad; Faber, Daniel; “Lunar Power & Light Company -- Orchestrating the Technology Development, Demonstration, and Deployment (TD^3) Missions needed to foster electrical utilities for Cislunar space.” - International Space Development Conference (ISDC) 2017, Space Solar Power Symposium, St. Louis, MO – Presentation May 26, 2017.
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33. Barnhard, G.P., Faber, D., "Space-to-Space Power Beaming - A Commercial ISS Technology Development, Demonstration, and Deployment (TD^3) Mission ", paper prepared for AIAA Space 2017 Orlando (Canceled). Republished in NSS Space Settlement Journal, November 2017.
34. Barnhard, Gary Pearce – "XISP-Inc Commercial ISS Space-to-Space Power Beaming Technology Development, Demonstration, and Deployment (TD^3) Mission" – IEEE Wireless in Space Extreme Environments (WiSEE) 2017, Space Solar Power Workshop, Montreal, Canada.
   – Presentation October 10, 2017.
35. Anzaldua, Al; Barnhard, Gary; Dunlop, David; Phipps, Claude – "A path to a commercial orbital debris cleanup, power beaming, and communications utility, using technology development missions at the ISS", The Space Review November 6, 2017
36. Barnhard, Gary Pearce – "XISP-Inc Commercial ISS Space-to-Space Power Beaming Technology Development, Demonstration, and Deployment (TD^3) Mission", 20th Annual DE S&T Symposium 2018 Power Beaming Metrology, Safety And Applications Session Challenges of Power Beaming Panel Input, Oxnard, California – Presentation & Poster Session February 27, 2018
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38. Barnhard, Gary Pearce – "XISP-Inc Commercial ISS Space-to-Space Power Beaming Technology Development, Demonstration, and Deployment (TD3) Mission", International Solar Power Satellite Symposium & Workshop (SSP-2018) ISDC 2018, Los Angeles, California – Presentation May 24, 2018
39. Barnhard, Gary Pearce, Potter, Seth Douglas "Challenges of Space Power Beaming: Forging production services from the technology development trade space ", AIAA Space 2018 Orlando, Florida – forthcoming Paper and Presentation September 19, 2018

7.2 Principal Investigator Selected Publications, Presentations and Papers:

Academic:

SPaCE-I: Spacecraft Preliminary and Conceptual Engineering I, UMCP Aerospace Engineering Department Technical Report TR 84-1 (Published thesis/proposal)

SPaCE-II: Spacecraft Procedures and Concepts Evaluator – 2, EER Systems -- (December 1986)

Space Station Program Documentation Tree:

NASA GSFC Technology Development Missions, Space Station Mission Requirements Working Group Data Base submissions (co-author with David Suddeth).

Robotic Systems Integration Standards (RSIS):

Volume I Accommodation Requirements, SSEIC Technical Lead Volume II Interface Standards, SSEIC Technical Lead

Mobile Servicing Centre Systems Requirements Document, SSEIC Technical Lead

Special Purpose Dexterous Manipulator Systems Requirements Document, SSEIC Technical Lead

Professional (circa 2005 to present):

1. Barnhard, Gary Pearce – "Architecting the Future", International Space Development Conference (ISDC) 2005 Washington, DC (May 2005) – Presentation and Panel Discussion
2. Barnhard, Gary Pearce – "Architecting the Future", International Space Development Conference (ISDC)

2006 Los Angeles, CA (May 2006) -- Presentation

3. Barnhard, Gary Pearce – “Architecting the Future - Thinking Outside the Box”, Advanced Technology Working Group (ATWG) Dallas, TX (May 2007) – Presentation/Facilitated Discussion
4. Barnhard, Gary Pearce – “Lunar Settlement Architecture Planning - Making the Best of Intentions Real, Can We Do It?” Advanced Technology Working Group (ATWG) Washington, DC (May 2008) -- Presentation
5. Barnhard, Gary Pearce – “Lunar Settlement Architecture Planning - Making the Best of Intentions Real, Are We Ready For It?” International Space Development Conference (ISDC) 2008 Washington, DC (May 2008) -- Presentation
6. Barnhard, Gary Pearce – “Architecting the Future - Engineering Better Outcomes for ISS, COTS, Ares V, Lunar Operations, and NASA”, International Space Development Conference (ISDC) 2009 Orlando, FL (May 2009) -- Presentation
7. Barnhard, Gary Pearce – “Is There a Business Case for Space Based Solar Power for Terrestrial Applications?”, Advanced Technology Working Group Meeting, NASA ARC December 9, 2008 – Presentation, debate with Dr. Pete Worden, and ATWG Workshop Facilitator
8. Barnhard, Gary Pearce – “Debating the Point: A Recent Discussion on the Topic of Space Solar Power”, International Space Development Conference (ISDC) 2010 Chicago, IL (May 2010) -- Presentation 1st NSS Space Solar Power Symposium
9. Barnhard, Gary Pearce – “The Wild Card – Commercial Communications for Exploration and Science”
– International Space Development Conference (ISDC) 2010 Chicago, IL (May 2010) – Presentation and Panel Discussion
10. Barnhard, Gary Pearce – “Mission Development Forum” – International Space Development Conference (ISDC 2011) Huntsville, AL – Facilitator & Systems Engineering Review Panelist (May 2011)
11. Barnhard, Gary Pearce – “Turning good ideas into gold - blazing a trail through the technology development valley of death” – International Space Development Conference (ISDC) 2012 -- Presentation and Panel discussion Washington, DC (May 26, 2012)
12. Barnhard, Gary Pearce -- "XISP - Xlink Internet Services Protocol” -- International Space Development Conference (ISDC 2012) Washington, DC -- presentation and panel discussion May 26, 2012.
13. Barnhard, Gary Pearce – “Commercial Delay Tolerant Pervasively Networked Point-of-Presence Gateway System for ISS” -- AAS/NASA/CASIS 1st Annual ISS Research and Development Conference Denver, CO – Presentation June 26, 2012
14. Barnhard, Gary Pearce – “Commercial Delay Tolerant Pervasively Networked Point-of-Presence Gateway System for ISS”, AAS 12-670, Proceedings of the 1st ISS Research and Development Conference, Results and Opportunities – The Decade of Utilization Vol 114 Science and Technology Series, AAS 2013
15. Barnhard, Gary Pearce, presentation – “Suspending Disbelief - Unbundling Space Power Systems to foster applications of Space-to-Space Power Beaming”, International Space Development Conference (ISDC) 2013, San Diego, CA May 25, 2013
16. Barnhard, Gary Pearce – “Space-to-Space/Surface Power Beaming”, AAS / NASA / CASIS 2nd Space Station Users Conference, Denver, CO – Poster session July 16, 2013
17. Barnhard, Gary Pearce, poster session – “Interoperable Network Communications Architecture”, AAS / NASA / CASIS 2nd Space Station Users Conference, Denver, CO – Poster session July 16, 2013
18. Barnhard, Gary Pearce – “Suspending Disbelief -- Unbundling Space Power Systems to foster applications of Space-to-Space Power Beaming”, IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) Space Based Solar Power Workshop, Baltimore, MD – Presentation November 8, 2013
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25. G.P. Barnhard – "Space to Space Power Beaming -- A Commercial Mission to Unbundle Space Power Systems to Foster Space Applications", AIAA 21st Improving Space Operations Support Workshop, Pasadena, CA – Presentation May 6, 2015
26. Barnhard, Gary Pearce; Dahlstrom, Eric; Chew, Ethan – "Halfway to Anywhere" - AIAA 21st Improving Space Operations Support Workshop, Pasadena, CA – Presentation May 6, 2015
27. Barnhard, Gary Pearce – "Interoperable Network Communications Architecture" - AIAA 21st Improving Space Operations Support Workshop, Pasadena, CA – Presentation May 6, 2015
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29. Barnhard, Gary Pearce – "Space to Space Power Beaming -- A Commercial Mission to Unbundle Space Power Systems to Foster Space Applications" - International Space Development Conference (ISDC) 2015, Toronto, Canada – Presentation Space Solar Power Track May 22, 2015
30. Barnhard, Gary Pearce – "Evolvable Communications Infrastructure on ISS and Interoperating Flight/Ground Systems" - International Space Development Conference (ISDC) 2015, Toronto, Canada – Presentation Lunar Workshop May 23, 2015
31. Barnhard, Gary Pearce, "Unbundling Space Solar Power Systems" Future In Space Operations (FISO) Colloquia – Presentation
32. Barnhard, Gary Pearce, "Unbundling Space Solar Power Systems" - 4th Annual ISS R&D Boston, MA – Poster Session July 2015
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54. Barnhard, Gary Pearce – "Lunar Power & Light Company: Orchestrating the Technology Development, Demonstration, and Deployment (TD^3) Missions needed to foster an electrical power and ancillary services utility for Cislunar space", International Solar Power Satellite Symposium & Workshop (SSP-2018) ISDC 2018, Los Angeles, California – Presentation May 23, 2018
55. Barnhard, Gary Pearce – "XISP-Inc Commercial ISS Space-to-Space Power Beaming Technology Development, Demonstration, and Deployment (TD^3) Mission", International Solar Power Satellite Symposium & Workshop (SSP-2018) ISDC 2018, Los Angeles, California – Presentation May 24, 2018
56. Barnhard, Gary Pearce, Potter, Seth Douglas "Challenges of Space Power Beaming: Forging production services from the technology development trade space ", AIAA Space 2018 Orlando, Florida – forthcoming Paper and Presentation September 19, 2018

7.3 SSPB Mission Consortium Key Collaborators Selected Papers, Presentations, Articles, and Books

In addition to the Principal Investigator's work, many of the core participants in the XISP-Inc consortium have similar, if not more prolific, publication lists, many of which are germane to the SSPB mission, which are available on request.

Proposal Section VIII: Additional Information

8.1 Letters of commercial support and/or cost sharing

Letters of commercial support and/or cost sharing have been previously obtained from these named SSPB Mission Consortium participants:

- XISP-Inc
- Barnhard Associates, LLC
- Raytheon, Inc.
- Northrop Grumman Innovation Systems (formerly Orbital ATK).
- Immortal Data, Inc.
- Made In Space, Inc.
- Blue Canyon Technologies, Inc.
- AIRBUS DS, Inc.
- Oceaneering
- Deep Space Industries, Inc.
- Tethers Unlimited, Inc.

The following companies have approached XISP-Inc and expressed interest in being a customer for power and/or ancillary services:

- United Launch Alliance
- ViaSat
- Blue Origin
- Northrop Grumman Innovation Systems (formerly Orbital ATK)
- Made In Space, Inc.
- Orbit Fab, Inc.

Letters of commercial support and/or cost sharing will be updated based on this proposal for inclusion in an unpaginated Appendix.

8.2 Letters of commitment from consultant* collaborators

Letters of commitment from consultant* collaborators identifying their area of expertise and affirmation of their willingness in principle to perform the required work at a defined rate if the SSPB mission execution funding have been obtained from these named XISP-Inc SSPB Mission Consortium consultants:

- Seth Potter – Beam Forming & Space Systems Engineering
- Brad Blair – Commercial Mission Development & Economics
- Joseph Rauscher – Cooperative Agreements and Administration
- David Cheuvront – Space Systems Engineering
- Ken Ford -- Program Implementation & Space Systems Engineering
- John Mankins – Space Solar Power & Technology Development
- Paul Werbos – Energy/Physics Modeling & Technology Development
- Richard Dickinson – Power Beaming & Technology Development
- Michael Doty – Systems Integration
- Aaron Harper – Communications & Data Systems Engineering
- Tim Cash – RF Systems Testing
- Brahm Segal – RF/Power systems engineering, test, verification & validation
- Tom Nugent – Optical Systems Testing
- Christopher Cassell – Orbital Dynamics
- Ed Belbruno -- Orbital Dynamics
- Eric Dahlstrom -- Space Systems Engineering

**In some cases, consultants may and likely will become direct employees of XISP-Inc*

Letters of commitment from consultant collaborators will be updated based on this proposal for inclusion in an unpaginated Appendix:

8.3 Letters of support, declarations of interest and/or cost sharing opportunities from other entities

Letters of support, declarations of interest and/or cost sharing opportunities from other commercial entities that have expressed interest but have no currently assigned SSPB Mission tasking are available from these potential XISP-Inc SSPB Mission Consortium participants on request:

Other Commercial Entities

- Pickens Innovations, Inc. (Tim Pickens, et al.) – Potential Collaborator – Technology Development
- Dynetics, Inc. (David Hewitt, et al.) – Potential Collaborator – Propulsion
- Booz | Allen | Hamilton (Marc Halada, et al.) – Potential Collaborator – Beaming Technology
- SSL (Laurie Chappel, et al.) – Potential Collaborator – Spacecraft Technology
- Sierra Nevada Space Systems (John Roth, et al.) – Potential Collaborator – Dreamchaser, etc.
- Northrop Grumman (Tatiana Vinogradova, et al.) – Potential Collaborator – SSP Project
- SpaceX (Gwynne Shotwell, et al.) – Potential Collaborator – Dragon I, II, etc.
- EXOS Aerospace & Technologies (John Quinn, et al.) – Potential Collaborator – Sarge, etc., and
- SpaceVR (Ryan Holmes, et al.) – Potential Collaborator – Hosted camera payload.

Letters of support, declarations of interest and/or cost sharing opportunities that are requested will be included in an unpaginated Appendix.

Government Entities

- Naval Research Laboratory (Paul Jaffe, et al.) – EMI/EMC, Thermal/Vacuum, and Multi-body testing
- NASA HEOMD
  - AESD – Division Chief & Deputy (Jason Crusan, et al.) – Potential Customer & Collaborator
  - SCaN – Cislunar Communications & Navigation Architect (Jim Schier, et al.) – Potential Customer & Collaborator
- DHS Customs and Border Protection (CBP) (Wolf Tombe, et al.) – Potential Customer & Collaborator
- AFRL SpROC – Invited Collaborator

Letters of support, declarations of interest and/or cost sharing opportunities that are requested will be included in an unpaginated Appendix.

Non-Profit Entities

- CASIS (Etop Esen, et al.) – Collaborator
- National Space Society (Michael Snyder, et al.) – Collaborator
- SPACE Canada (George Dietrich, Kieran Carroll, et al.) – Collaborator
- Space Development Foundation (David Dunlop, et al.) – Collaborator
- Heinlein Prize Trust – Potential Collaborator

Letters of support, declarations of interest and/or collaborative opportunities that are requested will be included in an unpaginated Appendix.

Universities

- University of Maryland Space Systems Lab (David Akin) – Collaborator
- University of North Dakota Space Systems Lab (Sima Noghanian) – Collaborator
- University of New Mexico COSMIAC Lab (Christos Christodoulou, et al.) – Collaborator

- St. Louis University (Michael Swartwout) – Collaborator
- Michigan Technical University, Michigan Technological University (Reza Zekavat) – Collaborator
- California Institute of Technology (Michael Kelzenberg, et al.) – Collaborators

Letters of support, declarations of interest and/or collaborative opportunities that are requested will be included in an unpaginated Appendix.

International Space Agencies
- Japanese Exploration Agency (JAXA) – Potential Collaborator awaiting NASA guidance
- Canadian Space Agency (CSA) – Potential Collaborator awaiting NASA guidance
- European Space Agency (ESA) – Potential Collaborator awaiting NASA guidance
- Russian Space Agency (ROSCOSMOS) – Potential Collaborator (TBD)

Involvement of International Space Agencies that are signatories to the ISS Intergovernmental agreements require some level of coordination, if not collaboration, with NASA. Once the NASA role in the XISP-Inc SSPB Mission NASA participation is sufficiently defined, the available terms for coordination and/or collaboration with the international space agencies can be negotiated. Since the SSPB mission involves the JEM Exposed Facility and/or the ESA Columbus Bartolomeo Exposed Facility, by definition JAXA and/or ESA are involved. Since the SSPB mission involves the use of the Mobile Servicing Centre by definition, CSA is involved. Since the SSPB mission involves potential EMI and EMC concerns by definition, all ISS partners would need to be cognizant of the mission parameters. Whatever coordination and or collaborative arrangements are agreed to will be documented and executed in the usual and customary manner.

8.4 NASA Prior SSPB Related Proposal Review Comments Disposition.

1) XISP-Inc received input from NASA JSC Code OZ regarding our January 20, 2017 submittal on the RESEARCH OPPORTUNITIES FOR ISS UTILIZATION NASA Research Announcement: NNJ13ZBG001N Soliciting Proposals for Exploration Technology Demonstration and National Lab Utilization Enhancements stated as follows: “NASA has determined that Space-to-space power beaming is of interest to NASA and has the potential to affect a wide range of missions and is a potential key element of space infrastructure for the future. Overall, the proposal [proposed mission] is relevant to NASA's exploration goals and reflects the involvement of a team with appropriate experience.” A consolidated comment/review disposition matrix follows in Tables 5A-5G – Consolidated Comment Disposition on XISP-Inc SSPB Proposal to NRA for ISS TD 2017. <u>Since the solicitation manager made the determination that the intention of XISP-Inc was for the SSPB mission to be commercial in nature, it was referred to CASIS for disposition, as CASIS deemed fit with no further concurrence from NASA necessary or required</u>.
2) XISP-Inc received input* from NASA Headquarters Space Technology Mission Directorate regarding our February 1, 2018 Mandatory Preliminary Proposal submittal on the “UTILIZING PUBLIC – PRIVATE PARTNERSHIPS TO ADVANCE TIPPING POINT TECHNOLOGIES APPENDIX to NASA Research Announcement (NRA): Space Technology - Research, Development, Demonstration, and Infusion – 2018 (SpaceTech–REDDI–2018), 80HQTR18NOA01 APPENDIX NUMBER: 80HQTR18NOA01-18STMD_001”. The review comments provided included:

- “It appears that the proposed effort fits within ST1 goals and objectives as stated in this solicitation. However, the description of the proposed effort is broad and it is unclear what the company is really offering in this proposed effort.”
- “The proposal provides sufficient justification of the current TRL level of 4 and evidence of previous work that has gone into this effort. However, the proposal does not provide sufficient detail on how the demonstration will significantly mature the technology.”
- “The proposed effort could offer significant commercial impact to a growing LEO small sat community, if achievable. However, the proposal does not provide details of anticipated product cost or comparison to

current cost and lacks sufficient description of why this technology is competitive."

- "The proposal does not provide sufficient detail to evaluate the commercial impact of the proposed capability as it depends on the intended target platform."
- "The proposed effort would offer positive NASA/OGA impact, if achievable. The proposal provides several examples of possible missions that could use this technology."
- "Availability of emergency power or power augmentation on demand could increase availability and security of many DoD programs."
- "[The] Adjectival Rating for Relevance [of the proposal was]: Good"
- "The [Rough Order of Magnitude] ROM [pricing] is not well justified. The cost of the proposed effort appears high given there is little technology development requirements and application of the proposed effort depends on established engineering methods and knowledge."
- "The proposal provides insufficient detail with respect to the industry contribution."
  **The SSPB mission development effort has addressed all the stated concerns raised in this review (proposal size was length limited).*

8.5 Use of Animal & Human Subjects

Proposals involving animals or humans require an assurance of compliance with appropriate oversight boards and their required provisions. Accordingly, the following representations are made:

- There are no human or animal test subjects associated with the SSPB mission.
- The use of crew for equipment deployment and experiment operations in the SSPB mission is incidental and consistent with standard operating procedures.
- All power beaming associated with the SSPB mission will be pointed away from the ISS into unobstructed space, and will be compliant with prevailing ISS EMI/EMC requirements.

8.6 XISP-Inc SSPB Mission Value Impact Summary

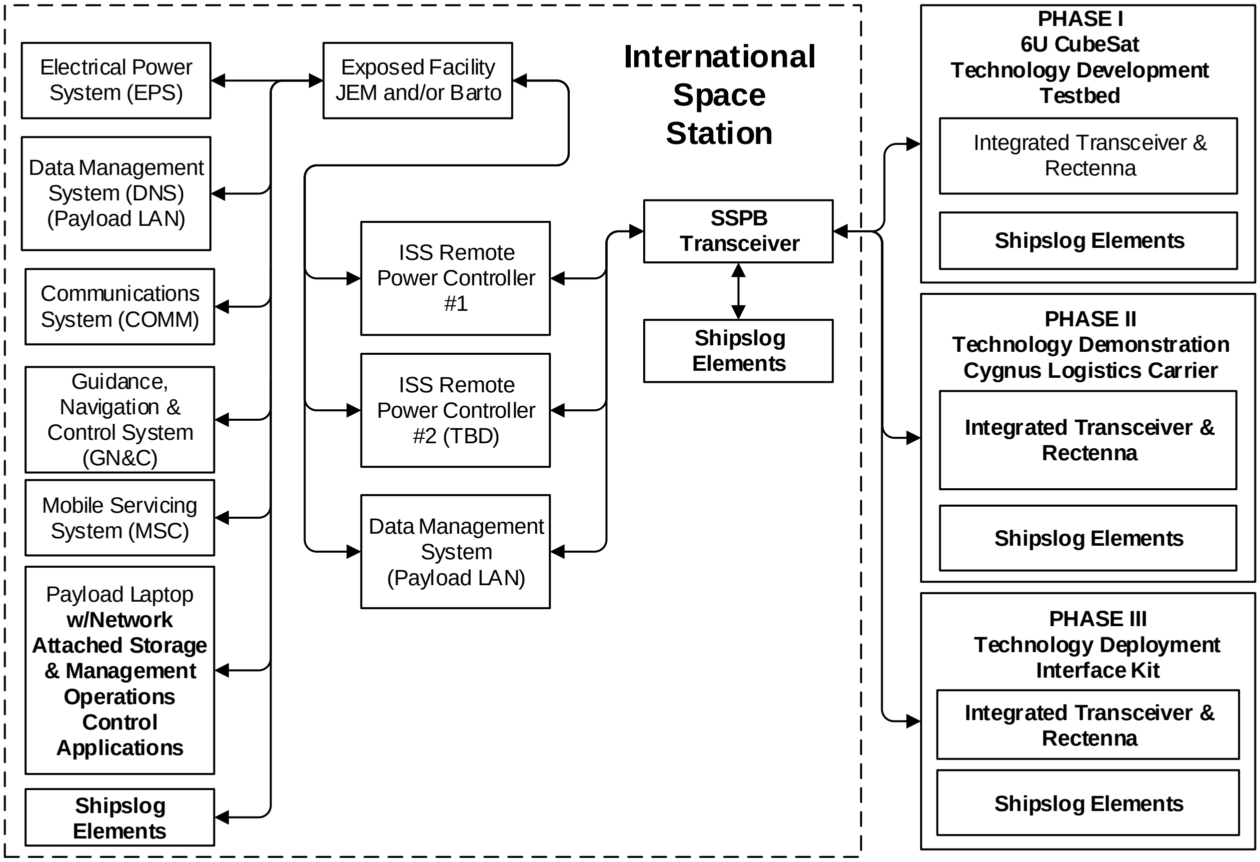
The XISP-Inc SSPB mission value impact summary, provided as Table 4 – XISP-Inc SSPB Mission Value Impact Summary, provides a single page impact summary for the SSPB mission.

Table 4 – XISP Inc SSPB Mission Proposed Value Impact		
Benefit	**Criteria**	**Assessment Factors**
ECONOMIC	**Application Leverage**	New addressable markets have been defined from LEO ISS co- orbiting through to the surface of the Moon.
	Market Innovation	Project creates a market for electrical power and ancillary services utility serving Cislunar space.
	New Revenue Potential	Incremental partner revenue accrues with each deployment within a proven addressable market segment.
INNOVATION	**Discovery/Science**	Project provides technology that is mission enhancing and in many cases mission enabling, and is scalable.
	Research Leadership	Project — provides XISP-Inc a leadership position in the space utilities market and helps prove out the value of CASIS.
	Unique Niche	The project requires access to the ISS. The project is critical to fostering space development. It leads to infrastructure for which there is little incentive for other government, commercial, or academic investment on a unilateral basis.
HUMANKIND / SOCIAL	**Building Enduring Capability**	At project completion, it will have provided the means to buy down the cost, schedule, and technical risk sufficient to serve as a foundation for the development of the Lunar Power & Light Company™.
	Catalytic	Space development requires available electrical power and ancillary services.
	Human Benefit	If successful, the project will prove out that there are economies of scale with respect to the generation and distribution of electrical power and ancillary services in space.
FEASIBILITY	**Project Clarity**	The project has clearly defined goals, progression, and path to market. There is a clear WBS.
	Resource Commitment	Partner has already invested more than the requested CASIS mission development grant. The Mission Consortium has the resources to finish and commercialize the results.
	Technical Approach	The execution plan is reasonable. The team has been vetted. The research methodology is robust and likely to succeed.
	Commercialization	There are multiple clear paths / mechanisms to enable the commercialization and use of the technology.

Table 4 – XISP Inc SSPB Mission Proposed Value Impact

Follow-On Activities – Phase II & III

Phase I success will be followed by a separate Phase II mission demonstrating the use of SSPB to provide power and ancillary services to a specially configured Cygnus pressurized commercial cargo carrier, and thereby raising the Technology Readiness Level (TRL) of SSPB technology from 5/6 to 8/9. XISP will then finalize evaluation of the potential for a space-based power and ancillary services utility for multiple applications. Phase II and any subsequent phases will be proposed separately.



SSPB Mission Interface Block Diagram

Table 14A-G – NASA Comment Disposition on XISP-Inc SSPB Proposal to NRA for ISS TD 2017

Number	Comment			Disposition
1	Space-to-space power beaming is of interest to NASA and has the potential to affect a wide range of missions, and is a potential key element of space infrastructure for the future	1.1	☑	Immediate mission opportunities in development include: (1) ISS Co-orbiting systems (2) Satellite servicing, power and ancillary utility services (3) emerging Lunar commercial prospector campaign and other international surface missions.
2	Overall, the proposal is relevant to NASA's exploration goals and reflects the involvement of a team with appropriate experience.	2.1	☑	The XISP-Inc team is evolving both in terms of technical depth, breadth, and sector participation.
3	However, based upon the details of the proposal and the review of it performed by multiple organizations across the agency, we are not able to fund the proposed effort at this time.	3.1	☑	While no NASA direct FY2017 Funding was allocated, the potential for NASA direct funding was left as an opportunity for discussion. This was reinforced by subsequent comments from the NASA Associate Administrator for HEOMD.
4	In addition to the lack of funding availability, the review process provided several comments that may be of use to you in future proposal development.	4.1	☑	The NASA review process has generated a range of comments that should be addressed in subsequent proposals. This review matrix tracks the disposition of each.
		5.1	☑	The XISP-Inc team is detailing the ground test program based on requested access to leverageable equipment, facilities, and personnel as well as more clearly articulating what must be demonstrated in space in this proposal and related papers.
		5.2	~	XISP-Inc needs to explicitly state the rationale for space versus ground test for the ISS mission:
		5.2.1	☑	Responsiveness of propulsion system in space can’t be done on ground
		5.2.2	☑	Responsiveness of pointing systems of CubeSat in 0-g cannot be done on ground in a cost-effective manner.
		5.2.3	☑	Measurement of power beam in space as affected by vacuum, thermal environment, solar wind and solar storm conditions cannot be done on ground in a cost-effective manner if at all.
		5.2.4	☑	Measurement of thermal management of CubeSat systems under space conditions of 90 minute orbital cycle cannot be done on ground in a cost-effective manner if at all.
		5.2.5	☑	XISP-Inc is requesting access to excess DOD Active Denial System equipment for ground test.
		5.3	~	XISP-Inc needs to explicitly state the rationale for space for space-to-lunar surface and lunar surface-to-lunar surface applications:

Number	Comment			Disposition
5	It was the opinion of at least one reviewer that it is not clear what requires in-space demonstration at this time that cannot be demonstrated on the ground.	5.3.1	☑	Keep alive power to last through the lunar night as well as power to support operations in Lunar Permanently Shadowed Regions (PSRs) can and should be part of the commercial resource prospector campaign ground engineering tests.
		5.3.2	☑	XISP-Inc is part of the emerging NASA ARC/NASA Headquarters effort to define options for equipment to live through the lunar night and operate in PSRs.
		5.3.3	☑	XISP-Inc is part of the Cislunar 1000 Lunar Propellant Mining Subgroup effort to define options for lunar volatiles mining in PSRs.
		5.3.4	☑	The combination of eutectic materials, batteries, equipment power cycling, beaming and other forms of transported/generated energy should all be considered in the design for Keep alive as well as power for operations in PRRs.
		5.3.5	☑	Ground based power transfers schedules can mirror the schedule that might be accomplished from lunar elliptical orbits.
		5.3.6	☑	What might be determined from ground thermal testing is how many lunar day night cycles commercial lunar prospectors could survive if stay alive power beaming was provided. Ground testing could demonstrate a very different mission profile capability.
		5.3.7	☑	The ground testing described above would reveal if the current PV arrays are sufficient to provide power transfer to charge the batteries and keep essential electronics warm. The PV array itself would have to survive the thermal cycles. So the thermal cycle life time of these arrays could determine if technology development for robust long duration thermal cycles are needed.
		5.3.8	☑	Pointing and tracking requirement for the ISS mission might take advantage of the existing LIDAR system for tracking used by OrbitalATK and Space-X for ISS approach and docking for cargo delivery. This system would determine the precise distances measurements in real time for measurement of power transfer and for measurement of the near field. I believe that there was a star tracker. Both the LIDAR and a radio signal from the ISS might also be used to point the power beaming satellite. Perhaps more detailed information on these systems and their use in controlling the spacecraft thrusters would be useful.

Number	Comment			Disposition
6	If technology development is needed to reach flight readiness, that path should be well described.	6.1	☑	Where satisfactory and sufficient XISP-Inc will be using COTS equipment, leveraging the specific vendors, testing experience, component flight history, and TRL 9 demonstration of efficiencies. The TRL levels for all components have now been explicitly addressed.
7	Pointing and tracking requirements as well as CubeSat GNC requirements should be expanded (for station keeping and de-orbit).	7.1	☑	The ISS is a platform whose capabilities and environment are known and well characterized. The beaming pointing capabilities of the Ku & Ka band dishes are known and well characterized. The extension to W band and higher frequencies based on the beam characterization, optimization, and definition/delineation of operational rules is not expected to yield in any way untractable point and tracking requirements. The initial NASA GN&C team assessment was that dwell time in the co-orbiting position outside the 200 meter Keep Out Sphere in the ram, starboard with a zenith bias position specified would be limited by available propellant and ISS reboost timing. Simulation models using STK are being developed to prove out the propellant load required for station keeping, retrieval (if tractable), and deorbit.
8	It was expressed that, in general, the proposal had insufficient details on the specific technologies proposed (rectenna, CubeSat, propulsion, beam pointing, and efficiencies) to demonstrate that a significant advancement of the state-of-the-art was present or that the proposed technologies are ready for an in-space demonstration.	8.1	☑	Since there are no operational Space-to-Space power beaming systems as clearly indicated by the assessed TRL, the foundational actions of this mission would at a minimum be a demonstration of the same with existing technology. The fact that increasing the frequency and various other specified design element enhancements to the specified components could materially impact efficiency and would therefore be traded is integral to the SSPB mission. Optimal rectenna design, cost effective CubeSat flight test articles, non-toxic propulsion systems, effective highly controllable beam pointing and increasing achievable end-to-end efficiencies are all part of the SSPB mission.
9	We appreciate your willingness to partner with us to fully utilize the ISS as a research platform.	9.1	☑	XISP-Inc, NASA, and CASIS seem to be on the same page in these regards.
10	A clear description of the business model XISP hopes to enable with this demonstration and how the demonstration will enable that business model.	10.1	☑	The business model must demonstrate the existence of potential customers for power beaming services of various kinds and the potential investment in comparison with the projected revenue stream associated with customer demand.
11	Does this help inform space to ground power beaming capabilities?	11.1	☑	The SSPB mission is intended to help mitigate perceived and actual cost, schedule, and technical risk associated with the use of space solar power technology and radiant energy beaming. Space-to-lunar surface applications are a significant aspect of the evolving XISP-Inc power beaming mission.

Table 14A-G – NASA Comment Disposition on XISP-Inc SSPB Proposal to NRA for ISS TD 2017

Number	Comment			Disposition
12	Do not ignore any potential earth bound benefits	12.1	☑	While it is possible to hold forth at length about the potential value of space solar power technology for Earth applications, it is the XISP-Inc position that doing something real with the technology now and providing for its incremental enhancement can be both mission enhancing and mission enabling. Accordingly, the XISP-Inc SSPB mission is focused on near-term Space-to-Space, Space-to-Lunar surface, and Lunar Surface-to-Lunar Surface applications. More distance Space-to- Earth applications and potential extension of the technology experience acquired in space is intended to be a fruitful area for follow-on work leveraging the SSPB mission efforts.
13	…not sure what the specific technical challenge that XISP is trying to solve other than the big picture idea? We are not convinced that there is any "there there" or new technology with what XISP is proposing.	13.1	☑	A - A space qualified Space-to-Space power beaming system of demonstrable value is a technical "there there". A frequency-agnostic power and ancillary services beaming system with greater end-to-end efficiencies and suitability for use in multiple addressable Cislunar markets as proposed by the SSPB mission bring even more to the table. B - The technical challenges XISP is addressing involve the use of higher frequencies (W band to eyesafe optical) for power and ancillary services transmission to improve end-to-end efficiencies for specific applications that have not been previously demonstrated on the ISS or elsewhere in space. C-The Space to lunar surface mission is meeting the challenge of the lunar thermal cycle with lunar surface equipment by initially providing a demonstration of stay alive power during the lunar night cycle or in permanently shadowed regions. RTGs might provide a much more expensive mechanism for sustained stay alive capabilities in the lunar cryogenic environment were sufficient material available or affordable. Specific use of highly elliptical orbits is another innovative aspect of addressing power supply challenges. These orbits, distances, and schedules are one way to provide power that can be shown to be feasible in other contexts such as ground demonstrations.
14	…Insufficient detail to assess if the company's cash and in-kind contributions are allowable to meet the cost sharing goal.	14.1	☑	XISP-Inc is paying careful attention to the rules for Industry Contributions/cost sharing, taking note of what is allowable and more clearly articulating what the details of the contributions are from different SSPB Mission Consortium members. It should be noted that due to Non-Disclosure Agreements between XISP-Inc and many members and potential members of the SSPB Mission Consortium disclosing unregistered proprietary details including specific details of their In-kind contributions is not possible until the SSPB Mission Consortium Agreement is signed by all parties.
15	…The cost breakdown for Phase 1 and Phase 2 is not obvious.	15.1	☑	The cost breakout between the Technology Development and Technology Demonstration work has been clarified.

Number	Comment			Disposition
16	…The subsystem delivery dates and the critical path are not identified on the Integrated Master Schedule. The duration of individual tasks is not specified.	16.1	☑	The Integrated Master Schedule provided is Pro Forma at this point representing the known internal schedule bounds that must be accommodated for the defined mission scope and duration. Subsequent versions will include detailed sub task durations, element subsystem delivery dates and the critical path. A project development schedule will be developed with individual vendors' delivery, testing, and qualification schedules specified.
17	…it is not clear whether a space demonstration is required at this time. To that end, it would be useful for the proposers to address in more detail the question of what needs to be demonstrated in space that cannot be demonstrated in a ground experiment.	17.1	☑	XISP-Inc is committed to a ground test program using existing equipment to the extent that it can be made available, as well as the use of protoflight ground replicas as an integral part of the mission development for the flight hardware and the related technology development. See earlier comments with regard to in-space testing and ground testing.
18	…There were some technical gaps in the proposal that should be addressed before proceeding forward… The proposal should identify the band to be used, give convincing evidence that the required components are available to transmit and receive power at the chosen wavelength, and provide power and efficiency values for each element in the power transmission chain, as well as the end-to- end efficiency to be achieved.	18.1	☑	XISP-Inc has decided that the SSPB mission should be frequency agnostic, allowing the customer requirements and the ability to accommodate the same drive the choice of supported frequencies. More specifically, the frequency range of consideration will range from the high end of Ka Band, through W band, and up to eyesafe optical. The compelling evidence that the individual components exist that could make up an end-to-end Space-to-Space power beaming system can be found in the bench strength of the SSPB Mission Consortium. At a minimum, the SSPB mission will be able to build and field a demonstrable power beaming system operating between the high end of Ka Band and the low end of W Band with end-to-end efficiencies that can be useful for some number of applications. How far up the frequency spectrum the technology can be pushed/pulled is of the essence of the SSPB mission.
19	I've been impressed with the team-building you've done	19.1	☑	Update status and activities of team for the 2018 round
20	. . . but I'm not impressed with the technology. You've demonstrated engineering feasibility but not necessarily innovation – something pushing the state of the art that would warrant NASA investment.	20.1	☑	Selling the notion of Technology Development, Demonstration, and Deployment (TD^3) missions being both iterative and recursive will require a much clearer articulation. Demonstrating engineering feasibility of useful work, mission risk reduction, and enhanced mission value is the point of the mission.
		21.1	☑	Sage advice. While this proposal is a Technology Development, Demonstration, and Deployment (TD^3), its ultimate purpose is providing space-qualified technology applications for customer mission requirements on a commercial basis.

Number	Comment			Disposition
21	If your proposals are not technology (R&D) related, then you should just promote the commercial aspect of getting something space-qualified for a commercial application which I think is a different path.	21.2	☑	The Technology Development components of the SSPB TD³ mission are: 1) Systems/Subsystem Related: o Multi-band receiving antennas (rectennas) (Ka band, W band, and Optical) o Optimized Multi-band transceiver (Ka band, W band, and Optical) o Multi-band phased array transmission apertures (Ka band, W band, and Optical) o Radiant energy beaming control and safety interlock system o Water based thrusters for propulsion and active attitude control system 2) Ancillary Utility Related: o Power/Data/Communications/Navigation/Time Multiplexing within radiant energy beams o Power and allied utility waveforms for Software Defined Radios (SDR) o Converged Radio Frequency & Optical SDR electronics 3) Intersecting XISP-Inc Missions: o Interoperable Network Communications Architecture (INCA) – (interoperable communications networks to accommodate customer ancillary utility requirements) o Management Operations Control Applications (MOCA) – (near–real-time state models, NASA ARC Mission Control Technologies OpenMCT software suite) o Alpha Cube Sat (ACS) – (advanced CubeSat design: reflectarray rectenna design, SDR, integrated avionics package, thruster/attitude control systems, virtual operations center) o Halfway To Anywhere (HTA) – (bi-modal water and electric propulsion, Trajectory Insert Bus, low energy trajectory applications)
		22.1	☑	The Technology Demonstration components of the SSPB TD³ mission are: 1) Radiant energy beaming testbed (integrated evolvable/scalable power and ancillary utilities) 2) Characterization of radiant energy beaming (near real-time, integrated with control) 3) Optimization of radiant energy beaming (near–real-time, integrated with control) 4) Formulation and testing of operational rules for the use of radiant energy beaming 5) CubeSat (Flight Test Article) Technology Readiness Level advancement to TRL 8/9

Table 5 G – NASA Comment Disposition on XISP-Inc SSPB Proposal to NRA for ISS TD 2017 (7 of 7)

Number	Comment			Disposition
		21.2	☑	The Technology Deployment components of the SSPB TD³ mission are: 1) ISS Co-orbiting Radiant Energy Beaming (50 m - 1 km) o 6U CubeSat Mobile Servicing Center (MSC) captive test with existing or optimized transmitter o 6U CubeSat MSC released test with optimized transmitter & rectenna o OrbitalATK Cygnus pressurized logistics carrier test with optimized transmitter & rectenna o NanoRacks Commercial Airlock/free-flyer test with optimized transmitter & rectenna (proposed) o Made In Space manufacturing cell test with optimized transmitter & rectenna (proposed) 2) Evolved/scaled systems will address other markets for power and ancillary utilities delivery in LEO, MEO, HEO, GEO, Libration/Trajectory Waypoints, Lunar Orbits, and the Lunar Surface 3) Power and allied utilities delivery will progress as systems are fielded • Emergency ==> Servicing ==> Augment ==> Backup ==> Primary
22	I can tell you that “our” technology budget (including STMD as well as HEOMD) is not sufficient to address all of the technologies we need even if we limit our interest to those that show the potential for order of magnitude improvement in some performance measure. That requires knowing what current performance, x, is and showing compelling evidence that you have an approach that does 5x or 10x better.	22.1	☑	Sage advice. Comparing a 95 GHz Beam at 6 kW input power at 200 m (i.e., co- orbiting with the ISS), the power density is over an order of magnitude higher than Isc (Solar Constant).
		22.2	☑	Mission capabilities on the lunar surface could increase mission cost effectiveness by orders of magnitude via long duration operations.