Watts on the Moon Challenge
Phase 2 Rules, Rev 1 + Level 3 Note

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Revision Tracking Log

Section	Revision #	Description	Date
	0	Original Document	02/23/2022
Phase 2 Technical Requirements	1	Deleted: 2) Achieve a Total Effective System Mass below 150 kg.	03/07/2022

Important Terms Used in this Challenge

Artemis Program: A NASA program to land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before.

Competition Levels: Segments of the challenge in Phase 2. At the end of each Competition Level, teams will be evaluated on specific technical milestones and the best performing teams will advance to the next Competition Level. There will be three Competition Levels in Phase 2.

HeroX: A company that provides a platform that allows anyone to launch a crowdsourcing project in an area they care about. NASA has contracted with HeroX to support the administration and promotion of this Challenge.

Judging Panel: A panel of professionals and subject matter experts from government, academia, and industry who will evaluate and score Phase 2 Submissions.

NASA Load Bank: A programmable electrical load provided by NASA for the challenge that will receive measured, continuous power delivered by team's hardware.

NASA Power Source: A programmable power supply provided by NASA for the challenge that will supply measured electrical power during prescribed periods of time during testing of team's hardware. This is the only source of energy or power teams are permitted to use.

Ombudsman: A liaison available to help resolve disputes. Additional information regarding the ombudsman can be found in the Team Agreement.

Team: One or more individuals or organizations that have registered to compete in the Challenge.

Team Agreement: A legal contract that all teams must sign in order to register for the Challenge.

Total Effective System Mass: The result of an adjustment to Total System Mass that accounts for the end-to-end efficiency of the team's hardware. The adjustment is based on the approximate mass of additional power generation capacity that would be required to supply a less-than-100% efficient power transmission and energy storage system to meet the challenge power delivery requirements. Additional information about Total Effective System Mass and how it will be calculated can be found in Appendix F.

Total System Mass: The mass of all hardware required to deliver power according to the conditions shown in FIGURE 1 over a distance of 3 km. See Appendix F for additional information.

Technical Nomenclature Used in this Challenge

Atmospheric Pressure is expressed in Pascals (Pa).

Earth ambient conditions are the local atmospheric temperature and pressure where hardware testing may occur and which will not be adjusted to affect hardware capability or performance.

Electrical potential is expressed as volts (V). Unless otherwise specified, all systems are direct current (DC) or volts direct current (VDC).

Energy and **energy storage capacity** are expressed watt-hours (Wh)

Liquid Nitrogen is expressed as LN2.

Mass is expressed as kilograms (kg).

Power is expressed as watts (W).

Simulated lunar conditions are temperatures and vacuum that approximate conditions in permanently shadowed lunar polar craters. The conditions established for Competition Level 3 testing will not fully replicate the extreme cold and hard vacuum of the actual lunar environment.

Temperature on the lunar surface or under simulated lunar conditions is expressed in absolute temperature, kelvins (K).

Volume is expressed in cubic centimeters (cm^3).

Challenge Overview

The Watts on the Moon challenge seeks to attract innovative engineering approaches to integrating power transmission and energy storage in order to enable missions operating in the extreme cold vacuum of the lunar surface. Successful demonstrations from this challenge will complement ongoing NASA investments in lunar surface power generation.

Background and context

Under the Artemis program, NASA plans to return to the Moon using innovative technologies to explore more of the lunar surface than ever before and applying what we learn to take the next giant leap—sending astronauts to Mars.

This mission will require lunar surface power systems that can deliver continuous, reliable power to support various industrial activities as well as human habitation. However, new technologies and systems will be needed to address these needs. Specifically, NASA has identified two critical gaps for lunar surface power systems:

1. **Power Transmission** that can deliver power from a remote generation source to critical mission operation loads where a) power loads are frequently or permanently immersed in extreme cold; and b) there are large variations in average power loads versus peak power loads. NASA has significant interest in both wired and wireless transmission, and the challenge seeks to incentivize and demonstrate both types of solutions.

2. **Energy Storage** that can a) power mission operation loads when power generation is not available; and b) survive and operate in extreme cold environments.

Given that NASA will likely need to transport power systems to the lunar surface, maximizing system efficiency and minimizing system mass will be important to addressing both gaps.

Challenge goals

The Watts on the Moon Challenge is a $5 million, two-phase competition focused on addressing critical gaps in lunar surface power systems, specifically related to power transmission and energy storage.

NASA is seeking solutions that can be designed and built and then tested in simulated lunar conditions and are well-positioned to progress toward flight readiness and future operation on the lunar surface after the challenge.

Such solutions may also have important synergies with terrestrial energy needs, and this challenge is expected to help advance similar technologies for terrestrial application and commercialization.

Challenge is not focused on power generation

This challenge is not focused on power generation. Although power generation will be critical to activities on the lunar surface, NASA already has a variety of programs focused on developing and deploying power generation solutions.

Teams should not propose any power generation as part of their solution. Such proposals will not be evaluated by the judging panel.

Competition structure

Phase 1 of the competition launched in September 2020 and lasted eight months. Seven winners were announced in May 2021 and were awarded a total of $500,000 in prize purses.

Phase 2 of the competition will last approximately 30 months and award up to $4.5 million. Phase 2 will take place in three segments, called Competition Levels. In each Competition Level, eligible Teams will submit the required materials and will be evaluated on their submission and scored by the judging panel.

No Mission Scenario in Phase 2

Phase 1 of the challenge included a hypothetical mission scenario and mission activities that teams were asked to address. Phase 2 of the challenge includes no such mission scenario. Teams should address the Phase 2 Technical Requirements, as described below.

Competition Calendar

TABLE 1 provides an overview of the expected timeline for Phase 2. This calendar is subject to change, and any updates will be posted on the Challenge website: https://www.herox.com/WattsOnTheMoon.

TABLE 1.
Competition Calendar

Competition Level	Event	Duration and Timing	Date
Competition Level 1 (~6 months)	Phase 2 opens Competition Level 1 begins	--	February 23, 2022
	Registration deadline Competition Level 1 submissions due	~4 months after Phase 2 opens	June 15, 2022
	Competition Level 1 judging and winner selection	~2 months after submission deadline	June – August 2022
	Competition Level 1 winners announced End of Competition Level 1	--	August 2022
Competition Level 2 (~11 months)	Competition Level 2 begins	--	August 2022
	Competition Level 2 submissions due	~6 months after Competition Level 2 begins	February 8, 2023
	Site visits by observer groups (in-person or virtual)	~3 months after submission deadline	February 2023 – May 2023
	Competition Level 2 judging and winner selection	~2 months after site visits	May – July 2023
	Competition Level 2 winners announced End of Competition Level 2	--	July 2023
Competition Level 3 (~13 months)	Competition Level 3 begins	--	July 2023
	Competition Level 3 safety reviews Teams may continue working on submissions during this period	Up to 2 months prior to submission deadline	February – March 2024
	Competition Level 3 submissions due	~9 months after Competition Level 3 begins (includes up to 2 months for safety reviews)	April 3, 2024
	Testing at NASA	~3 months after submission deadline	April – July 2024
	Competition Level 3 judging and winner selection	~1 month after testing	August 2024
	Competition Level 3 winners announced End of Competition Level 3 and Phase 2	--	August or September 2024

Phase 2 Technical Requirements

In Phase 2, NASA is seeking solutions that:

1) Draw power from an intermittent NASA Power Source and deliver power continuously to a NASA Load Bank;
2) Operate in simulated lunar temperatures and vacuum;
3) Operate continuously without any additional power generation;
4) Demonstrate a capability to deliver power over a distance of 3 km; and
5) Optimize total system mass and total system efficiency.

Key performance requirements, environmental conditions, and assumptions are explained below.

Key performance requirements

NASA has designed a conceptual power load profile and environmental conditions intended to represent a portion of a lunar mission (see FIGURE 1). Teams are expected to design and build solutions that deliver power according to the profile shown in FIGURE 1.

PLEASE NOTE: As of November 2023, FIGURE 1 has been updated for Level 3 testing. The current version of FIGURE 1 can be found in the Competition Level 3 Technical Guidance <https://www.herox.com/WattsOnTheMoon/resource/1606>.

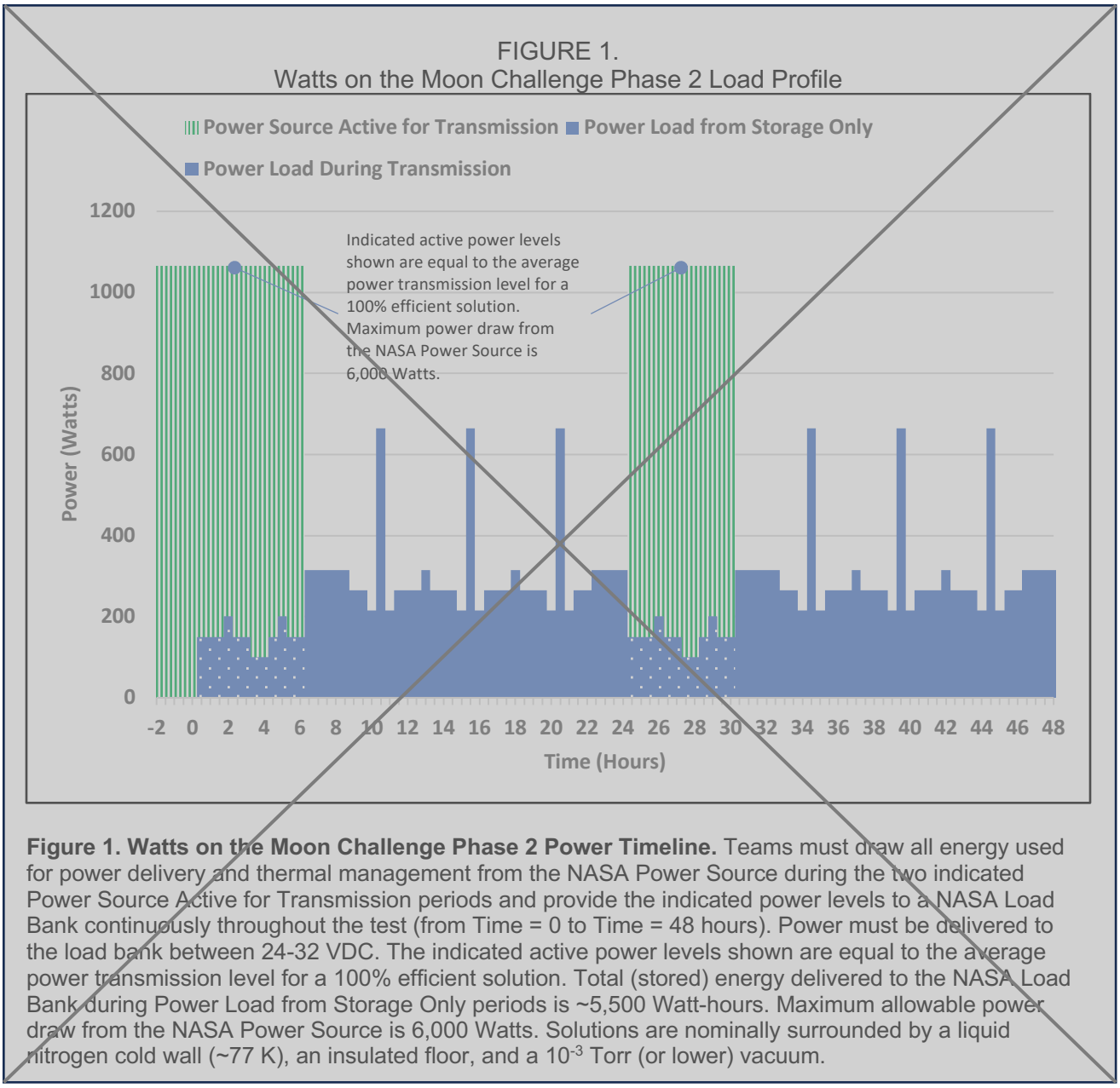


Figure 1. Watts on the Moon Challenge Phase 2 Power Timeline. Teams must draw all energy used for power delivery and thermal management from the NASA Power Source during the two indicated Power Source Active for Transmission periods and provide the indicated power levels to a NASA Load Bank continuously throughout the test (from Time = 0 to Time = 48 hours). Power must be delivered to the load bank between 24-32 VDC. The indicated active power levels shown are equal to the average power transmission level for a 100% efficient solution. Total (stored) energy delivered to the NASA Load Bank during Power Load from Storage Only periods is ~5,500 Watt-hours. Maximum allowable power draw from the NASA Power Source is 6,000 Watts. Solutions are nominally surrounded by a liquid nitrogen cold wall (~77 K), an insulated floor, and a 10^{-3} Torr (or lower) vacuum.

Explanation of relevant environmental conditions

This challenge does not seek to address all possible environmental conditions on the lunar surface, but rather, the key environmental conditions that represent critical technology gaps.

The relevant environmental conditions for this challenge are:

- **Temperature**: Phase 2 of the challenge is focused on solutions that will survive and operate at temperatures as low as 77 K. [1]

[1] We expect that, during Competition Level 3 testing, any energy storage and the termination component of any power transmission will be placed in close proximity of a radiative cold wall chilled with liquid nitrogen inside a thermal vacuum chamber.

- **Atmospheric Pressure**: Phase 2 of the challenge is focused on solutions that will operate at atmospheric pressure of 0.1 Pa (~10^3 torr or ~ 10^{-5} atmospheres) or lower.

Other environmental conditions on the lunar surface, such as dust and radiation, are not part of this challenge, and Teams are not required to address them.

Key assumptions

Teams should make the following assumptions in developing their solutions. Note, Teams are not responsible for the design or implementation of any features of any of the NASA Power Source or NASA Load Bank described below. In addition, Teams should not propose modification of the NASA Power Source or the NASA Load Bank as part of their solution.

- **Transport to the lunar surface**: This challenge is not focused on transporting solutions to the lunar surface. Teams should not address transport to the lunar surface in their submissions.

- **Deployment on the lunar surface**: Although Teams will not be required to *demonstrate* how their solution would be deployed on the lunar surface after landing, Teams will be required to *describe* methods and solutions to the challenges of post-landing surface deployment or set up of their power transmission designs under lunar-surface environmental conditions.

- **NASA Power Source**: This challenge is not focused on power generation. Teams should not propose any power generation as part of their solution. Such proposals will not be evaluated by the judging panel. Teams must deliver power ***from*** a NASA Power Source with the following characteristics:

    - Operates in a fixed location
    - Provides up to 6 kW of electrical power at 120VDC
    - Provides power only during time periods shown in FIGURE 1
    - Complies with the SAE International Space Power Standard AS5698 power quality specification

- **NASA Load Bank**: Teams must deliver power ***to*** a NASA load bank with the following characteristics:

    - Operates in a fixed location
    - Operates continuously and follows the load profile and timeline shown in FIGURE 1
    - Operates in constant power mode
    - Power must be delivered to the load bank between 24-32 VDC
    - Steps between load changes will be limited to slew rates less than 100 Watts per second (W/s)

- **Long Distance Power Transmission Demonstration**: Teams should assume that the NASA Power Source and NASA Load Bank are 3 km apart. All solutions must demonstrate power delivery over this distance through a combination of testing and analysis.

Phase 2 Competition Levels and Requirements

Phase 2 includes a registration period and three levels of competition. Each is explained in more detail below. Teams should note that, if they are chosen to participate in Competition Level 2, they must provide proof of insurance as outlined in the Team Agreement.

Registration

Any eligible individual or organization that meets the eligibility criteria provided in Appendix A may participate in Phase 2. Teams are not required to have participated in Phase 1.

To register, Teams must either upload the executed Team Agreement or provide the details required for HeroX to prepare and send the agreement, via RightSignature, for execution. To participate in Phase 2, Teams must execute the Team Agreement and other required documents by June 22, 2022 (7 days after the Competition Level 1 submission deadline).

Teams selected for an award will be required to provide proof of citizenship/permanent residency, proof of primary place of business, proof of incorporation, and/or proof of student visa. Proof must be provided within 3 business days to be eligible for an award. Any Team or team member who submitted the required proof documents in Phase 1 and was deemed eligible to compete will not be required to submit this documentation again in Phase 2. Teams must indicate which documents from Phase 1 should apply to Phase 2 entry and provide confirmation that all documents are still valid.

The registration process will be administered by HeroX. Registration will take place through the official Challenge website: https://www.herox.com/WattsOnTheMoon. Additional details regarding the process for registration are available on the challenge website.

Competition Level 1

In Competition Level 1, Teams will develop detailed engineering design and analyses of their solution, similar to what is required in an engineering preliminary design review. The Competition Level 1 Template outlines the specific elements that Teams must address and describes how each element will be scored. The Competition Level 1 Template is provided in Appendix B.

Teams will complete and submit the Competition Level 1 Template by the Competition Level 1 submission deadline, June 15, 2022, at 5:00 PM Eastern Daylight Time.

Following the submission deadline, the judging panel will review, evaluate, and score submissions. Up to seven (7) winning Teams will be awarded prizes and move onto Competition Level 2. Only winning Teams from Competition Level 1 will be permitted to participate in Competition Level 2. In addition, NASA personnel will review each winning Team's plan for Level 2 testing and analysis and indicate whether the plan is "sufficient" or "insufficient" with regard to each of the Competition Level 2 Performance Metrics (see Appendix C). Teams will receive an evaluation form indicating which areas are "sufficient" or "insufficient"; however NASA will not provide any specific notes or suggestions to Teams regarding their plans; Teams will be solely responsible for updating their plans (if necessary) and executing their plans in Competition Level 2, as described below.

Competition Level 2

In Competition Level 2, Teams will develop and demonstrate (through testing and analysis) key components of their solution, similar to what is required in an engineering critical design review. The purpose of Competition Level 2 testing and analysis is to demonstrate two aspects of their solution:

1) Feasibility of the design and progress toward environmental and performance testing in *Competition Level 3*;
2) Critical aspects of the design that, for practical reasons, *cannot be tested in Competition Level 3*.

The Competition Level 2 Template outlines the specific elements that Teams must address and describes how each element will be scored. The Competition Level 2 Template is provided in Appendix D.

In addition, prior to the Competition Level 2 submission deadline, Teams will be asked to confirm the location/facility that will be used for Competition Level 2 testing.

Teams will complete and submit the following three items by the Competition Level 2 submission deadline, February 8, 2023 at 5:00 PM Eastern Standard Time:

- A completed Competition Level 2 Template
- An updated Testing Plan for Competition Level 2
- A video demonstration file (if needed), as described in the Competition Level 2 Template

Following the Competition Level 2 submission deadline, NASA will send an observer group to conduct a site visit. Site visits will take place in person, unless COVID-19 or other conditions necessitate that site visits be conducted virtually. The observer group may include one or more NASA personnel and a member of the judging panel. During the site visit, Teams must conduct relevant activities outlined in their Testing Plan for Competition Level 2. During the site visit, the observer group will validate the performance results and ask any additional questions necessary to understand and assess the Team's performance. The observer group will record and submit their findings to the judging panel for consideration in judging.

Each site visit is expected to be completed within one day; all site visits will be completed within two months. Site visits may be conducted concurrently by different observer groups. Teams may request a specific date for their site visit; however, a Team's preferred date is not guaranteed. Teams will be provided with reasonable notice to confirm the date of the site visit. Additional details regarding site visits will be provided to Teams after Competition Level 2 commences.

Following completion of all site visits, the judging panel will review, evaluate, and score submissions. Up to four (4) winning Teams will be awarded prizes and move onto Competition Level 3. Only winning Teams from Competition Level 2 will be permitted to participate in Competition Level 3.

Competition Level 3

In Competition Level 3, Teams will refine their hardware and submit a full system prototype for testing in simulated lunar conditions at NASA facilities.

Up to two months before the Competition Level 3 submission deadline, Teams must complete a safety review to demonstrate that the Team's hardware will operate safely during Competition Level 3 testing. For this review, Teams must submit an updated version of the safety analysis they submitted in Competition Levels 1 and 2. This safety analysis must identify potential safety hazards and discuss how those hazards have been mitigated. Teams will make a virtual presentation of the safety analysis to a NASA safety committee. The committee must approve the safety of each Team's solution before it can be delivered to any NASA facility. If NASA cannot approve a Team's solution because the solution cannot be deemed sufficiently safe, the Team may be ineligible to test in a NASA facility and ineligible to win a prize.

Following NASA's approval of the safety analysis, Teams will submit the following items:

- All hardware required for Competition Level 3 testing
- An updated Master Equipment List, including both the hardware submitted for testing and the hardware required to deliver power over a distance of 3 km
- Calculation of Total System Mass, including supporting analysis that shows the difference between the mass of the hardware submitted for testing and the mass of the hardware required to deliver power over a distance of 3 km

Teams will provide these items by shipping or delivery to a NASA facility; the exact shipping address will be provided to Teams prior to the shipping deadline. The shipping deadline will be April 3, 2024.

The testing period for each Team is expected to last up to two weeks and will include integration of the Team's solution into the testing facilities and testing. Teams may participate in the hardware integration into the test facility under the observation and supervision of NASA. Teams are expected to have at least one team member, approved by NASA, present during the testing period. Teams may request specific dates for their testing period; however, a Team's preferred dates are not guaranteed.

Prior to Competition Level 3 installation and testing, NASA will measure the mass of hardware submitted. Potential adjustments to this mass measurement are discussed in Appendix F.

After a Team's solution has been integrated into the testing facilities but before testing commences, NASA will conduct a test readiness review. If test readiness is deemed insufficient, the Team will have up to two days to remedy any issue under NASA observation and supervision. If sufficient remedies cannot be made, the Team may not proceed with testing and will not be eligible to win. If any remedy impacts the mass of a Team's hardware, NASA will make any necessary adjustments to the mass measurement.

Following the test readiness review, NASA will conduct testing for each solution to determine its ability to deliver power to loads described in FIGURE 1 under simulated lunar conditions. Specifically, NASA intends to use a thermal vacuum chamber that will simulate the temperatures and atmospheric pressure described in FIGURE 1. Preliminary details regarding expected testing operations can be found in Appendix G. Any updated details and resources regarding testing operations will be provided at the challenge website.

During Competition Level 3 testing, NASA will determine the total system efficiency of each solution by the ratio of the energy delivered to the NASA Load Bank to the energy drawn from the NASA power source.

Teams will be scored based on Total Effective System Mass, which is equal to the Total System Mass plus Excess Power Mass Penalty, as described in the Competition Level 3 Scoring System. Additional details regarding scoring can be found in Appendix F.

Following testing, the judging panel will review, evaluate, and score the test results. Up to two (2) winners will be awarded prizes. Each team that participates in Competition Level 3 testing will also receive a facility testing report with their testing data and performance results.

Phase 2 Prize Purse

For eligibility to win a prize, see the Watts on the Moon Phase 2 Team Agreement.

NASA expects an available total prize purse for Phase 2 of up to $4.5 million. NASA will award prizes to the winners of each Competition Level, as described in TABLE 2 below.

TABLE 2.
Phase 2 Prize Purse Distribution

Competition Level	Number of Winners	Prize Purse per Winner	Total Prize Purses Awarded
Competition Level 1	Up to 7	$200,000	$1.40 million
Competition Level 2	Up to 4	$400,000	$1.60 million
Competition Level 3	Up to 2	1st place: $1,000,000 2nd place: $500,000	$1.50 million
Total			**$4.5 million**

Appendix A: Eligibility

NASA welcomes applications from individuals, teams, and organization or entities that have a recognized legal existence and structure under applicable law (State, Federal or Country) and that are in good standing in the jurisdiction under which they are organized with the following restrictions:

a. **Individuals must be** U.S. citizens or permanent residents of the United States **and must be** 18 years of age or older.
b. **Organizations must be** an entity incorporated in **and** maintaining a primary place of business in the United States.
c. **Teams must be** comprised of otherwise eligible individuals or organizations and led by an otherwise eligible individual or organization.

U.S. government employees may enter the competition, or be members of prize-eligible teams, so long as they are not acting within the scope of their federal employment, and they rely on no facilities, access, personnel, knowledge or other resources that are available to them as a result of their employment except for those resources available to all other participants on an equitable basis.

U.S. government employees participating as individuals, or who submit applications on behalf of an otherwise eligible organization, will be responsible for ensuring that their participation in the Competition is permitted by the rules and regulations relevant to their position and that they have obtained any authorization that may be required by virtue of their government position. Failure to do so may result in the disqualification of them individually or of the entity which they represent or in which they are involved.

Foreign citizens may only participate through an eligible US entity as:

I. An employee of such entity
II. A full-time student of such entity, if the entity is a university or other accredited institution of higher learning (Exhibit B),
III. An owner of such entity, so long as foreign citizens own less than 50% of the interests in the entity, **OR**
IV. A contractor under written contract to such entity.

Each individual, whether acting alone or as part of a Team, must identify his/her nationality. No Team Member shall be a citizen of a country on the NASA Export Control Program List Category II: Countries determined by Department of State to support terrorism. (The current list of designated countries can be found at **http://oiir.hq.nasa.gov/nasaecp/**). This includes individuals with dual citizenship unless they are a U.S. citizen or a lawful permanent U.S. resident (green card holder). Further, pursuant to Public Law 112-55, NASA is prohibited from participating, collaborating, or coordinating bilaterally in any way with China or any Chinese-owned company. Thus, NASA will review submissions to ensure no Team or Entity falls under this prohibition.

Appendix B: Competition Level 1 Submission Template

WATTS ON THE MOON CHALLENGE
PHASE 2 COMPETITION LEVEL 1
SUBMISSION TEMPLATE

INSTRUCTIONS

- This template must be saved as a PDF and uploaded using the HeroX application portal.

- The total page limit for the submission is 30 pages; Teams must adhere to this limit. A "page" is defined as 8 ½" X 11" size paper with 11-point font (Arial and 1-inch margins), single spaced. Any text included in tables, figures, or captions may be as small as 10-point font. The contents of any pages beyond page 30 of any submission will not be read or evaluated. This instruction section does not count toward the page limit and may be deleted prior to submission. Teams should maintain all numbered section headings in their submission.

- Each section includes a recommended length for the answer. These recommendations are intended to provide guidance on NASA's expectations for the length and quality of the answer, but Teams are not required to adhere to these recommendations. Teams may allocate space to different sections as they see fit.

- You must complete the Team Information section. If the Team Affiliations/Organizations does not apply to your Team, write "None." If you skip any of these fields, your submission will be returned to be corrected.

- You must answer all questions in the Your Solution section. Any answer that is blank will be deemed incomplete. Teams should not submit answers such as "see previous answer" or "not applicable." Such answers will be deemed incomplete. Any incomplete question will automatically receive zero points.

- Teams will be evaluated on each criterion on a 0-10 point scale, as described in the judging rubric in Appendix E. A total of 100 points is available. Points will be weighted as described below in TABLE 3. To be eligible for a Competition Level 1 award, Teams must receive a minimum score of 60 points (out of 100 points).

TABLE 3.
Scoring in Competition Level 1

Section	Weighting
1.1. Preliminary Engineering Design	25%
1.2. Key Analyses and/or Preliminary Test Results	25%
1.3. Preliminary Schematics	5%
1.4. Master Equipment List and Mass	10%
1.5. Safety Analysis	5%
2.Testing Plan for Competition Level 2	15%
3. Development Plan	5%
4. Risk Assessment	5%
5. Budget	5%
Total	**100%**

TEAM INFORMATION SECTION

Team Name: *(Teams are encouraged to use a creative team name. This name may be used in promotional materials related to the challenge.)*

Team Lead:

Team Affiliations/Organizations (if applicable):

Geographic Location (City and State/Territory):

One Sentence Description: *(Provide a one-sentence description of your solution that may be used in promotional materials related to the challenge. Do not reference any confidential elements of your solution in this description.)*

YOUR SOLUTION SECTION

1. Solution Design

1.1. Preliminary Engineering Design

1.1.1. A rationale for your design approach *(Recommended length: 2 pages)*

1.1.2. Preliminary evidence and analysis predicting performance including efficiency, mass, and specific energy of key components of the system *(Recommended length: 2-4 pages)*

1.1.3. System-level and component-level design specifications for hardware and software; in this section, you should include a description of the methods and solutions to the challenges of surface deployment or set up of your power transmission design under lunar-surface environmental conditions after a successful landing. *(Recommended length: 2 pages)*

1.1.4. Description of how the system and components will address the Phase 2 Technical Requirements section of the rules (which outlines the performance that Teams will be expected to demonstrate in Competition Level 3 testing) *(Recommended length: 2 pages)*

1.2. Key Analyses and/or Preliminary Test Results

1.2.1. Summary of concept of operations describing how your solution will address the conceptual load profile in FIGURE 1 *(Recommended length: 2-3 pages)*

1.2.2. Summary of power efficiency analysis and estimate of total system efficiency *(Recommended length: 2-3 pages)*

1.2.3. Summary of thermal analysis that addresses how your solution will tolerate/survive the environmental conditions in FIGURE 1 *(Recommended length: 2-3 pages)*

1.3. Preliminary Schematics *(Recommended length: 2 pages)*

Provide preliminary schematics for key elements of your solution (such as power, control, and fluids) and assembly-level CAD models showing envelopes and key dimensions

1.4. Master Equipment List and Mass

Use the following EQUIPMENT TEMPLATE to provide a draft master equipment list, including mass and volume estimates and descriptions of internal and external interfaces for the anticipated testing in Competition Level 3. *Estimated volume and interfaces will be used to help inform NASA's testing plan in Competition Level 3 and will not be evaluated by judges. (Recommended length: 1 page)*

EQUIPMENT TEMPLATE

Evaluated by Judges		*For Informational Purposes Only*		
Description of Equipment and Supplier	**Estimated Total System Mass (kg)**	***Estimated volume (cm^3)***	***Internal interfaces***	***External interfaces***

1.5. Safety Analysis *(Recommended length: 2 pages)*

1.5.1. Identify any potentially hazardous materials or other safety concerns related to your design and/or its operation that are relevant to testing your solution in a NASA facility in Competition Level 3.

1.5.2. Provide a safety analysis addressing future transport and operation of your solution on the lunar surface, including any interactions with the NASA assets described in the challenge rules and potential interactions with humans.

2. Testing Plan for Competition Level 2. *(Recommended length: 3 pages)*

Teams are expected to determine the testing and analysis necessary to demonstrate items under section 2.1 and 2.2 below. NASA expects that testing and analysis will include component-level testing and high-fidelity models and/or analyses. Teams are expected to address each of these performance metrics in your plan and describe in detail the testing or analysis that will be conducted.

2.1. To demonstrate feasibility of the design and progress toward performance that will be tested in Competition Level 3:

2.1.1. End-to-end efficiency of any power transmission system

2.1.2. Mass of any power transmission system

2.1.3. Roundtrip efficiency and energy capacity of any energy storage system

2.1.4. Mass of any energy storage system

2.1.5. Operation in temperatures and atmospheric pressures that will be tested in Competition Level 3

2.2. To demonstrate critical aspects of the design that, for practical reasons, cannot be tested in Competition Level 3:

2.2.1. Delivery of projected steady-state, maximum power over a 3 km distance between the power source and Load Bank, where the demonstration is either a full-distance test or a combination of a partial-distance test and emulation or analysis of extrapolation to the full distance. Teams demonstrating a full-distance test will receive a bonus in Level 2 scoring.

2.2.2. For energy storage systems, demonstration of 30 charge/discharge cycles 1) in Earth ambient conditions or a colder environment; 2) at a depth of discharge equal to the planned depth of discharge during operations in Competition Level 3 testing; and 3) with no more than 20% loss of energy capacity

2.2.3. Additional performance demonstrations recommended by the Team, if applicable

3. Development Plan *(Recommended length: 1 page)*

   Describe your plan for further developing your solution during Competition Level 2 and Competition Level 3. Teams should address the technical steps necessary for hardware development; personnel and other resources; and timeline in relation to the Competition Level 2 and Competition Level 3 submission deadlines.

4. Risk Assessment *(Recommended length: 1 page)*

   Describe the technical and other risks associated with developing your solution in Competition Level 2 and Competition Level 3. For each risk, Teams should include an assessment (such as high, medium, low) and your proposed risk mitigation strategy.

5. Budget *(Recommended length: 1 page)*

   Use the following BUDGET TEMPLATE to describe the budget necessary to execute the plan described in your answer to Section 3. In the “Expected funding sources” column, Teams should address whether you will already have funds in place to support work during Competition Level 2 and Competition Level 3, and if not, how you will secure the necessary funds. You may assume the Competition Level 1 prize purse in your budget.

BUDGET TEMPLATE

Type of cost	**Description**	**Necessary budget for Competition Level 2**	**Necessary budget for Competition Level 3**	**Expected funding source(s)**
Materials				
Equipment				
Lab/testing				
Personnel				
Other				
Other				

Appendix C: NASA Review of Competition Level 2 Testing and Analysis Plans

As noted, following the announcement of Competition Level 1 winners, NASA personnel will review each winning Team's plan for Competition Level 2 testing and analysis and indicate whether the plan is "sufficient" or "insufficient" with regard to each of the Competition Level 2 Performance Metrics (see TABLE below). NASA will not provide any specific notes or suggestions to Teams regarding their plans; Teams will be solely responsible for updating their plans (if necessary) and executing their plans in Competition Level 2, as described in the competition rules.

TABLE 4 illustrates a sample evaluation form feedback that Competition Level 1 winners may expect to receive regarding their plan for testing and analysis.

TABLE 4.
Sample Evaluation Form Provided to Competition Level 1 Winners

Competition Level 2 Performance Metric	**Evaluation of Team's Plan**
End-to-end efficiency of any power transmission system	Sufficient
Mass of any power transmission system	Sufficient
Roundtrip efficiency and energy capacity of any energy storage system	Insufficient
Mass of any energy storage system	Sufficient
Operation in temperatures and atmospheric pressures that will be tested in Competition Level 3	Insufficient
Delivery of projected maximum power over a 3 km distance between the power source and load, where the demonstration is either a full-distance or a combination of a partial-distance test and emulation or analysis of extrapolation to the full distance.	Sufficient
For energy storage systems, demonstration of 30 charge/discharge cycles 1) in Earth ambient conditions or a colder environment; 2) at a depth of discharge equal to the planned depth of discharge during operations in Competition Level 3 testing; and 3) with no more than 20% loss of energy capacity	Sufficient

Appendix D: Competition Level 2 Submission Template

WATTS ON THE MOON CHALLENGE
PHASE 2 COMPETITION LEVEL 2
SUBMISSION TEMPLATE

INSTRUCTIONS:

- This template must be saved as a PDF and uploaded using the HeroX application portal.

- The total page limit for the submission is 30 pages; Teams must adhere to this limit. A "page" is defined as 8 ½" X 11" size paper with 11-point font (Arial and 1-inch margins), single spaced. Any text included in tables, figures, or captions may be as small as 10-point font. The contents of any pages beyond page 30 of any submission will not be read or evaluated. This instruction section does not count toward the page limit and may be deleted prior to submission. Teams should maintain all numbered section headings in their submission.

- Each section includes a recommended length for the answer. These recommendations are intended to provide guidance on NASA's expectations for the length and quality of the answer, but Teams are not required to adhere to these recommendations. Teams may allocate space to different sections as they see fit.

- You must complete the Team Information section. If the Team Affiliations/Organizations does not apply to your team, write "None." If you skip any of these fields, your submission will be returned to be corrected.

- You must answer all questions in the Your Solution section. Any answer that is blank will be deemed incomplete. Teams should not submit answers such as "see previous answer" or "not applicable." Such answers will be deemed incomplete. Any incomplete question will automatically receive zero points.

- Teams will be evaluated on each criterion, as described below in TABLE 5. For some criteria, Teams will receive points on a 0-10 point scale, as described in the judging rubric in Appendix E. For other criteria, Teams will be scored on a Pass/Fail basis. Teams will receive a score of "Pass" if they successfully demonstrate the performance described in the respective criterion. A total of 110 points is available, including a 10% bonus for Teams that demonstrate a full distance test (as described below in TABLE 5). Points will be weighted as described below in TABLE 5. To be eligible for a Competition Level 2 award, Teams must 1) receive a minimum score of 60 points (out of 110 points); and 2) receive no more than one "Fail" on the criteria scored Pass/Fail.

TABLE 5.
Scoring in Competition Level 2

Criteria		Weighting
PERFORMANCE DEMONSTRATIONS AND RESULTS		
Feasibility and progress toward performance tested in Competition Level 3 (including the quality and fidelity of sections 1.1 and 1.2 of the template and the performance results)	End-to-end efficiency of any power transmission system and roundtrip efficiency and energy capacity of any energy storage system	20%
	Mass of any power transmission system and mass of any energy storage system	20%
	Operation in temperatures and atmospheric pressures that will be tested in Competition Level 3	20%
Critical performance that cannot be tested in Competition Level 3 (including the quality and fidelity of section 1.2.4 of the template and the performance results)	Delivery of projected maximum power over a 3 km distance between the power source and load, where the demonstration is either a full-distance test or a combination of a partial-distance test and emulation or analysis of extrapolation to the full distance.	Scored Pass/Fail and teams that demonstrate a full distance test will receive bonus points in the amount of 10% of their total score
	For energy storage systems, demonstration of 30 charge/discharge cycles 1) in Earth ambient conditions or a colder environment; 2) at a depth of discharge equal to the planned depth of discharge during operations in Competition Level 3 testing; and 3) with no more than 20% loss of energy capacity	Scored Pass/Fail
	Additional performance metrics recommended by the team (if applicable)	Scored Pass/Fail
1.3 Updated Schematics		5%
1.4 Master Equipment List and Mass		10%
1.5 Safety Analysis		10%
3. Development Plan		5%
4. Risk Assessment		5%
5. Budget		5%
TOTAL		**100% + 10% bonus (as explained above)**

TEAM INFORMATION SECTION

Team Name:

Team Lead:

Team Affiliations/Organizations (if applicable):

Geographic Location (City and State/Territory):

One Sentence Description: (*Provide a one-sentence description of your solution that can be used in promotional materials related to the challenge. Do not reference any confidential elements of your solution in this description*)

YOUR SOLUTION SECTION

1. Solution Design (Updated from Competition Level 1 submission)

    1.1. Updated Engineering Design

        1.1.1. Updated rationale for your design approach (*Recommended length: 1-2 pages*)

        1.1.2. Updated evidence and analysis predicting performance including efficiency, mass, and specific energy of key components of the system (*Recommended length: 2-4 pages*)

        1.1.3. Updated system-level and component-level design specifications for hardware and software (*Recommended length: 2 pages*)

        1.1.4. Updated description of how the system and components will address the Phase 2 Technical Requirements section of the rules (which outlines the performance that Teams will be expected to demonstrate in Competition Level 3 testing) (*Recommended length: 2 pages*)

    1.2. Key Analyses and/or Test Results

        1.2.1. Updated summary of concept of operations describing how your solution will address the conceptual load profile in FIGURE 1 (*Recommended length: 2-3 pages*)

        1.2.2. Updated summary of power efficiency analysis and estimate of total system efficiency (*Recommended length: 2-3 pages*)

        1.2.3. Updated summary of thermal analysis that addresses how your solution will tolerate/survive the environmental conditions in FIGURE 1 (*Recommended length: 2-3 pages*)

        1.2.4. Summary of testing and/or analysis that support critical performance that cannot be tested in Competition Level 3 (see PERFORMANCE RESULT TEMPLATE below) (*Recommended length: 1-2 pages*)

    1.3. Updated Schematics (*Recommended length: 1-2 pages*)

Provide schematics for key elements of your solution (such as power, control, and fluids) and assembly-level CAD models showing envelopes and key dimensions

1.4. Master Equipment List and Mass

Use the following EQUIPMENT TEMPLATE to provide an updated master equipment list, including mass and volume estimates and descriptions of internal and external interfaces. Estimated volume and interfaces will be used to help inform NASA's testing plan in Competition Level 3 and will not be evaluated by judges. (*Recommended length: 1 page*)

EQUIPMENT TEMPLATE

Evaluated by Judges		***For Informational Purposes Only***		
Description of Equipment and Supplier	**Estimated Total System Mass (kg)**	***Estimated volume (cm^3)***	***Internal interfaces***	***External interfaces***

1.5. Updated Safety Analysis (*Recommended length: 2 pages*)

1.5.1. Identify any potentially hazardous materials or other safety concerns related to your design and/or its operation that are relevant to testing your solution in a NASA facility in Competition Level 3.

1.5.2. Provide an updated safety analysis addressing future transport and operation of your solution on the lunar surface, including related to any interactions with the NASA assets described in the challenge rules and potential interactions with humans.

2. Performance Results (*Recommended length: 1 page*)

2.1. Using the PERFORMANCE CRITERIA TEMPLATE below, record the performance results achieved through testing or analysis prior to submission. You will then be expected to demonstrate those results during the observer visit. You should address the performance metrics listed below that are relevant to your solution; you may also add additional performance metrics specific to your solution.

NASA expects that your performance results at the site visit will be similar or better than the performance results provided in the submission. If your performance at the observer visit on any metric is less than performance result in the submission by more than a reasonable margin of error (10%), the judges will reduce your score for that metric.

If validation of a performance metric cannot be conducted during the observer visit (because, for example, a test cannot be completed in one day), you may submit a video demonstration of that performance for that metric in addition to this template.

PERFORMANCE CRITERIA TEMPLATE

Performance Metric	**Performance result at submission**	**Performance result recorded during the observer visit**	**Performance result demonstrated in a video**
End-to-end efficiency of any power transmission system			
Mass of any power transmission system			
Roundtrip efficiency and energy capacity of any energy storage system			
Mass of any energy storage system			
Operation in temperatures and atmospheric pressures that will be tested in Competition Level 3			
Delivery of projected maximum power over a 3 km distance between the power source and load, where the demonstration is either a full-distance test or a combination of a partial-distance test and emulation or analysis of extrapolation to the full distance.			
For energy storage systems, demonstration of 30 charge/discharge cycles 1) in Earth ambient conditions or a colder environment; 2) at a depth of discharge equal to the planned depth of discharge during operations in Competition Level 3 testing; and 3) with no more than 20% loss of energy capacity			
Additional performance recommended by the Team, if applicable			

Additional performance recommended by the Team, if applicable			

3. Development Plan (*Recommended length: 1 page*)

   Describe your plan for further developing your solution during Competition Level 3. Teams should address the technical steps necessary for hardware development; interface validation; personnel and other resources; and timeline in relation to Competition Level 3 submission deadline.

4. Risk Assessment (*Recommended length: 1 page*)

   Describe the technical and other risks associated with developing your solution in Competition Level 3. For each risk, Teams should include an assessment (such as high, medium, low) and your proposed risk mitigation strategy.

5. Budget (*Recommended length: 1 page*)

   Use the following BUDGET TEMPLATE to describe the budget necessary to execute the plan described in your answer to Section 3. In the "Expected funding sources" column, Teams should include whether you will already have funds in place to support work during Competition Level 3, and if not, how you will secure the necessary funds. You may assume the Competition Level 2 prize purse in your budget.

BUDGET TEMPLATE

Type of cost	**Description**	**Necessary budget for Competition Level 2**	**Necessary budget for Competition Level 3**	**Expected funding source(s)**
Materials		N/A		
Equipment		N/A		
Lab/testing		N/A		
Personnel		N/A		
Other		N/A		
Other		N/A		

Appendix E: Judging Rubric in Competition Levels 1 and 2

In Competition Levels 1 and 2, each judge will assign points to each Team based on an evaluation of each Team's submission. Each judge will assign points for each criterion based on a 0-10 point scale, as described in TABLE 6. Points will be weighted according to importance and relevance to the challenge, as described in Appendix B: Competition Level 1 Submission Template and Appendix D: Competition Level 2 Submission Template, respectively.

TABLE 6.
Judging Rubric in Competition Levels 1 and 2

Range of Points Awarded	Description
0	The Team has not addressed the criterion
1-3	The Team has addressed the criterion but provided incomplete or insufficient information to adequately evaluate quality
4-6	The Team has provided a sufficient answer, but the supporting documentation or analysis does not meet a high level of credibility or fidelity
7-9	The Team has provided a sufficient answer, and the supporting documentation or analysis meets a high level of credibility or fidelity
10	The Team has exceeded expectations in demonstrating the credibility, fidelity, and performance of their solution

Appendix F: Competition Level 3 Scoring

In Competition Level 3, Teams will be evaluated and scored based on the performance of their solution in a simulated lunar environment at NASA facilities.

Teams that successfully deliver power[2] under the conditions described in FIGURE 1 for 100% of the timeline in FIGURE 1, will receive a score equal to their Total Effective System Mass, as follows:

Total Effective System Mass =
Total System Mass *plus* Excess Power Mass Penalty

Where:

- **Total System Mass** = The mass of all hardware required to deliver power according to the conditions shown in FIGURE 1 over a distance of 3 km. Specifically in Competition Level 3, the measured weight of hardware submitted for testing in Competition Level 3 may be adjusted to accommodate hardware to demonstrate the full 3 km power transmission distance based on the testing and/or analysis performed in Competition Level 2. See Notes on Total System Mass Adjustments below.

- **Excess Power Mass Penalty[3]** = (Average Source Power *minus* Average Source Power for a 100% efficient system) *multiplied by* 0.01 kg/W

- **Average Source Power** (W) = Total energy (Wh) provided by the NASA Power Source when it is providing power during the second recharging period (between hours 24 and 30), *divided by* 6 hours.

- **Average Source Power for a 100% efficient system** is estimated to be 1,065 W.

If no Team successfully delivers power under the conditions described in FIGURE 1 for 100% of the timeline in FIGURE 1, then all Teams will receive a score based on their Total Effective System Mass and Power Timeline Performance, as follows:

Total Effective System Mass =
(Total System Mass *plus* Excess Power Mass Penalty)
***divided by* Power Timeline Performance**

Where:

- **Power Timeline Performance** = The fraction of the full timeline in FIGURE 1 during which power was delivered to the NASA Load Bank within the voltage ranges specified.

Notes on Total System Mass Adjustments

[2] NASA plans to measure whether Teams have successfully delivered power over the required timeline by measuring power quality. The power quality measurement will occur at a specified connector in the chamber wall, and power quality must stay within the specifications of the NASA Load Bank, including between 24-32 VDC.

[3] The inefficiency of the transmission and energy storage systems place additional burdens on the power source, causing it to be scaled up. This penalty is meant to account for the additional power source mass that a Team's solution would require to meet the technical challenge.

Depending on the characteristics of the solution, Teams may replace elements used to demonstrate, emulate, or analyze the full distance in Competition Level 2 with alternative elements suitable for the much shorter distance in the thermal vacuum chamber. The mass of the alternative elements used in Competition Level 3 testing will be deducted from the total measured hardware mass and replaced by the mass of hardware required to achieve the full 3 km distance as demonstrated and/or analyzed during Competition Level 2.

For example:

- Wireless power transmission solutions may provide different or extra hardware to tailor the energy beam properties for the much shorter distance. The mass of this alternative hardware will be deducted from the total measured hardware mass and replaced by the mass of the hardware required to transmit the beam over a 3 km distance as demonstrated or analyzed during Competition Level 2.

- Wired power solutions may use either a full-length cable or a shorter cable plus a hardware-based emulation of the entire 3 km in Competition Level 3. If a cable plus emulation is used, the mass of cable emulation hardware will be deducted from the total measured hardware mass and replaced by the mass of a 3 km cable as demonstrated or analyzed during Competition Level 2.

Following the calculation of scores, the judging panel will verify the the accuracy of each Team's score and rank Teams from lowest score to highest score. Scores will be whole numbers; decimal points below 0.50 will be rounded down and decimal points of 0.50 or higher will be rounded up.

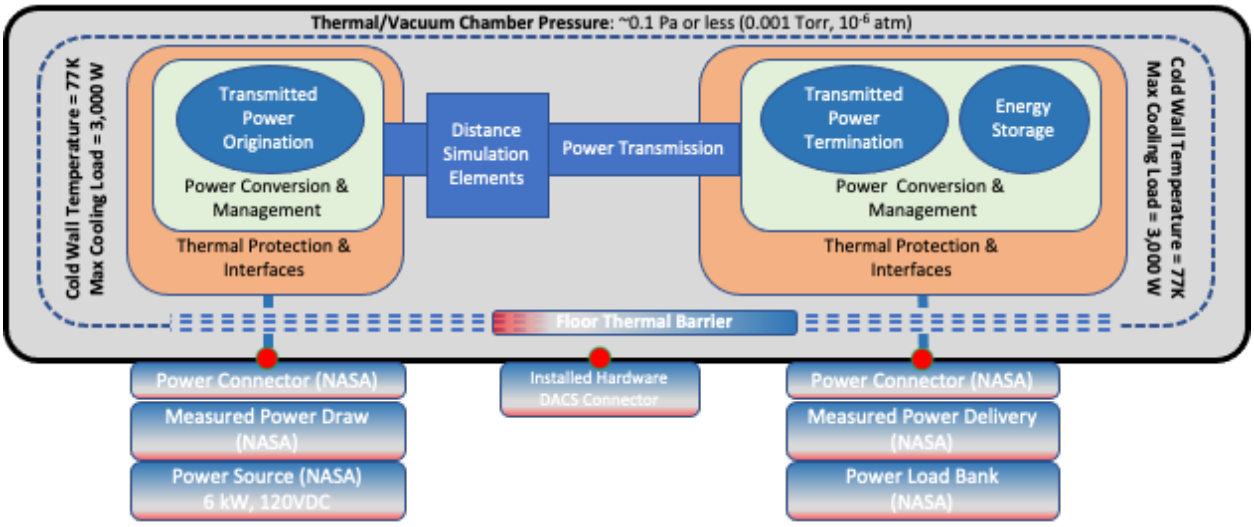
The grand prize winner will be the Team with the lowest score. The second prize winner will be the Team with the second-lowest score. In the event of a tie, the judging panel will break the tie based on the respective Teams' performance in Competition Level 1 and Competition Level 2.

Appendix G: Preliminary Testing Operations in Competition Level 3

The following are preliminary details regarding expected testing parameters and operations in Competition Level 3. Any updated details and resources regarding testing parameters and operations will be provided on the challenge website.

The expected testing configuration is illustrated in FIGURE 2 below.

FIGURE 2
Expected Testing Configuration in Competition Level 3



For Competition Level 3 testing, a Team's solution will be installed in a thermal vacuum chamber. For safety reasons, energy storage will be installed in the chamber at no greater than 50% state of charge.

Teams will be required to deliver power in the thermal vacuum chamber over an actual distance significantly shorter than 3 km, and most likely in the range of 2-10 m. The exact distance and any other related parameters will be updated once a testing facility has been chosen.

All hardware located between the indicated NASA power connectors will count for the Total System Mass measurement.

A NASA power source will provide up to 6 kW at 120VDC during limited periods, as described in FIGURE 1. Measured power draw will be provided to a specified connector in the chamber wall.

A NASA power load bank requires power delivery continuously, including periods of peak power, as described in FIGURE 1. Power quality measurement will occur at a specified connector in the chamber wall.

The thermal vacuum chamber will provide a nominally uniform temperature environment (77 K) in the form of a liquid nitrogen cold wall and a 10^3 Torr or lower vacuum . The chamber floor will be insulated to simulate the thermal properties of the lunar surface. A Team's solution will not be permitted to physically contact anything other than the insulated chamber floor (except for electrical connections).

One NASA multi-pin connector will be provided for solution hardware data acquisition and top-level (on/off) control (DACS). All system power management functions must be conducted inside the chamber.