Task 6. Request for Proposals: NASA: Long-term Water Storage in Spacecraft without Biocides

2023

Task proposed by NASA, Ames Research Center

Task sponsored by New Mexico Space Grant Consortium

Updated 10/18/22 to incorporate BVAD, replace the TEA with ESM, and further develop bench-scale testing.

Background

In preparation for the Artemis program's Lunar and Mars missions, NASA challenges you to design a means of indefinitely ensuring the potability of stored water supplies on a spacecraft or a planetary base without using biocides or other high-maintenance approaches.

Teams are urged to be creative because this is an issue of great importance to the Artemis program, and for which NASA does not currently have a solution. Designs having sufficient merit will be invited for consideration on a lunar mission.

Artemis Program Infrastructure

The Artemis program will establish a long-term sustainable presence on the moon, supporting lunar missions of up to two months to study technologies to prepare for missions to Mars. NASA plans for initial touchdown on the lunar south pole by 2025, beginning with shorter stays and advancing to longer stays during follow-on missions.

Artemis Base Camp will be the lunar base consisting of three main modules: the Foundational Surface Habitat, the Habitable Mobility Platform, and the Lunar Terrain Vehicle. Gateway is a planned small space station in lunar orbit that will be used in conjunction with Artemis missions. It is intended to serve as a solar-powered communication hub, science laboratory, and short-term habitation module. For both Gateway and the Artemis Base Camp, occupancy will be intermittent, with long periods of dormancy between missions. It is important that the facilities remain truly dormant between missions, with no need for upkeep or maintenance.

The water supply will be potentially exposed to microbes during periods of intermittent occupation. Such periods are expected to be approximately one month in duration.

Long-term Water Potability in Space

Ensuring the potability of stored water supplies in both the base camp and Gateway facilities is particularly important in the radiation environment of space where microbial mutations can be accelerated. Therefore, maintaining potability of stored water is a key mission requirement as stated in the 2020 NASA Technology Taxonomy and the NASA Strategic Technology Framework.

The use of biocides such as iodine or silver is the current state-of-the-art technology for microbial control in spacecraft. However, since biocides react with microbes and other molecules, they are consumed with time and must be continuously added to the water to ensure that their concentration remains above a critical threshold.

This results in a resupply requirement and the need to continually recirculate water through the distribution system to ensure proper mixing and exposure of the biocide in all areas of the water storage and distribution system.

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Although biocides have worked well for previous NASA missions, their need for continual maintenance is not compatible with the Artemis program, for which up to 11 months of dormancy are planned. The requirement to add biocides and continuously recirculate the water during dormancy periods is particularly problematic as it means that the habitat must remain operational and cannot be in a truly dormant state.

Another problem with biocides is that they do not kill all of the bacteria, and with time, the organisms can mutate and become resistant to the biocide. Hence, microbial populations must be regularly monitored to assess mutations and the potential need to modify the biocide.

The ideal solution to this challenge is to ensure that organisms cannot grow, which will ensure that mutations cannot occur.

Equivalent System Mass—NASA's Economic Evaluation for Launch

With space exploration, everything comes down to mass. Anything to be put into space is launched initially from the earth's surface and must overcome Earth's gravity. The more mass something has, the more energy, and hence the greater cost, is needed to achieve launch. Therefore, in lieu of the typical Techno-Economic Analysis (TEA) that engineers perform as part of the economic justification for an RFP, NASA utilizes the Equivalent System Mass (ESM) when evaluating competing technologies to solve a particular problem.

The ESM concept measures the cost of launching a particular system on a spacecraft; it requires that every component used and every resource consumed by a system be converted to a mass value using accepted equivalent standard conversion factors. [See Levri, et al. to learn more about the ESM approach.]

For the purpose of this task, the base equation used in Levri, et al. is simplified below. Keep in mind that this equation is for illustrative purposes and is not dimensionally consistent.

ESM = mass + volume + power + thermal load

where

- mass = mass (kg) of the equipment needed for your technology
- volume = overall volume (such as m^3) occupied by your technology, including empty interstitial space
- power = power (such as kilowatts (kW)) consumed by your technology
- thermal load = rate of heat (again, such as kW) ejected to the surroundings by your technology

The units of mass are already correct. To change the other terms to units of mass, they must be multiplied by a normalized volume, power, or thermal load (kg/m3, kg/kW, and kg/kW, respectively). Such conversion terms have been determined by NASA and are used in calculations such as this. The relevant NASA document containing these conversions is called "Baseline Values and Assumptions" (BVAD) and it is available from WERC only after a team is fully registered for this task.

Keep in mind that NASA considers the BVAD to be semi-proprietary, so it is important not to share the document with anyone not needing to see it nor to post it online or distribute it to the public in any way. When not in use, any paper copies must be kept secured.

You should calculate the ESM for your proposed solution and include it as part of your reporting in the same way you would report a TEA for non-space-related tasks. Keep in mind that keeping the ESM as low as possible is important because, given competing technologies that solve the same problem, NASA will choose the technology with the lower ESM.

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Problem statement

Your team will research, evaluate, and design a means of storing 2400 liters of potable water indefinitely on a spacecraft or a planetary base without using technologies that would require maintenance during periods of dormancy, such as biocides. Attention must also be given to ensuring the sterility of the water distribution plumbing.

Teams are given full design freedom for the scaled-up water-storage and or water-delivery design, including materials used. Teams are urged to be innovative in their approach and consider physical, chemical, and/or thermal means of achieving the desired results.

Note that the primary goal is to ensure that bacteria cannot grow in the water. Your design does not necessarily need to kill bacteria that is in the water.

Design requirements

Your proposed design should provide specific details and outcomes as follows:

- Design a system that can be scaled up to storing a minimum of 2400 liters of potable water indefinitely in space habitats and space stations. The design should:
    - Ensure long-term sterility of water distribution plumbing.
    - Remain fully dormant while maintaining water potability during periods of non-occupancy that may last up to 11 months.
    - Minimize mass, volume, and power consumption
    - Minimize maintenance when in use by the crew.
- Ensure that the design can operate independent of gravity and/or be operable in reduced gravity conditions similar to on the moon (⅙ Earth's gravity).
- Provide a complete process diagram illustrating all components of your design and their functions. If warranted, consider this diagram to be a process flow diagram that shows all inputs, outputs, and processes.
- Report results of your Equivalent System Mass (ESM) calculations as outlined above. This is in lieu of the typical WERC Environmental Design Contest TEA required of most tasks.
- Identify and address the fate of any waste products generated by the treatment technology.
- Include a public involvement plan, as applicable (see Team Manual).
- Every team that participates in the WERC Environmental Design Contest can be considered for the WERC P2 Award. To be considered, in a separate section of the report (titled "Pollution Prevention"), document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project.
- Address any intangible benefits of the selected treatment process.
- Address safety aspects of handling raw materials needed for construction and/or operation of the system as well as any final products. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above. In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but shall not be substitutes for the bench-scale demonstration.

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<u>On-site Bench-scale Testing</u>

Your team will design and build a bench-scale water-containment system that holds a minimum of 2 liters and a maximum of 18 liters of water for use during the bench-scale demonstration that can be scaled up to a water-storage system that holds 2400 liters of water. As this project may require a complete change in NASA's current water-storage infrastructure, you are encouraged to design your own water storage tanks and supply lines.

<u>Bench-scale Synthetic Solution</u>

During the bench-scale demonstration, each team will be provided with up to 18 liters (a 5-gallon container) of synthetic solution that will consist of dechlorinated tap water to which a non-pathogenic strain of *E. coli* has been added. The synthetic solution will remain in all teams' designed systems for the same amount of time (approximately 48 hours). At the end of the storage period, your team will be asked to submit three 100-mL samples of effluent from your water-storage system for analysis.

<u>Pre-contest Bench-scale Testing</u>

Teams may test their designs at their home lab using a synthetic solution similar to that provided at the contest (Watch the FAQs for details about the particular *E. coli* strain that will be used at the contest).

<u>Analytical Testing Techniques at the Contest</u>

WERC will submit your team's effluent to our laboratories to test your system's ability to prevent bacterial growth in the provided synthetic solution.

<u>Reporting Bench-scale Testing Results in the Technical Report</u>

In the technical report, your team should report water quality (including potability) after storing the water for longer periods of time than is allowed at the on-site contest. As a goal, try to store the water for at least two weeks, longer if possible. Include plate counts.

30% Project Review

Suggested submission date: Feb. 6, 2023
Final submission date: February 24, 2023

An engineering "30% Project Review" reviews the engineering firm's preliminary design and aspects of a project with a client. It provides the client an opportunity to suggest modifications for inclusion in the final design. The goal is to define the scope of the project, present a project schedule, report progress to date to meet the final deadline, and determine fatal flaws, if any.

For the design contest, the review should not exceed four pages. Submit the project review as soon as possible. You are allowed to change your plans after submitting it. Although the review is not scored, your team will receive feedback from the judges for improving your project. (The higher the quality of your review, the more help you will get from the judges.)

At a minimum, the review must include:

- **A brief description of your project:** One bulleted list outlining: goals, planned solution to the problem, and any anticipated drawbacks.
- **A project schedule** (schedule for completion of the contest solution, including progress to date)
- **Process flow diagram** with all mass and energy balances, as needed.
- **Table of Contents** planned for the technical report (place topics in order, one line per topic)

Experimental Safety Plan (ESP)

The ESP outlines your team's plans for safely operating your bench-scale demonstration at the contest. This document is submitted in February (see dates below). Instructions are provided in the team manual. The Team Leader, or a designated team member, shall attend a mandatory short course that outlines the ESP process. Teams will not be able to run a bench-scale demonstration if the ESP is not received by the deadline. Your team should follow your school's safety procedures while conducting tests prior to attending the contest.

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Evaluation Criteria

Each team is advised to read the 2023 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in the manual, there are five events: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, a poster presentation, and a Flash Talk. Criteria used by the judges in evaluation of these five components are described in the Team Manual.

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website:

Guidelines | werc.nmsu.edu

Your response to the problem statement will include consideration of the following points specific to this task.

- Potential for real-life implementation, including expected reliability and maintainability.
- Thoroughness and quality of the process-flow diagram.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The results of your bench-scale demonstration: How effective is the treatment technology?
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs online).

Short Courses

WERC is offering two short courses:

- ***Mandatory:*** Preparing the Experimental Safety Plan. The Team Leader, or a person assigned by them, must attend the course prior to submitting the ESP (and before February 20, 2023).
- ***Optional:*** Environmental Health and Safety (EH&S). The course is designed to prepare teams to complete the EH&S portion of their technical report. Individuals can earn a digital badge to add to their professional development portfolio. Course fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration information.

Dates, Deadlines, FAQs (*dates subject to change—watch website FAQs*)

- Today: Email us to let us know you are interested in this task. We will contact you with breaking news.
- Opening mid-December, 2022: Optional Course: WERC Safety and Environmental Topics.
  Live—See website for dates and times. See Team Manual for more information.
- Opening mid-December, 2022: Mandatory Course: Preparing the Experimental Safety Plan.
  February 20, 2023: deadline for attending. On-demand—See website & Team Manual for information.
- February 6 - 24, 2023: 30% Project Review Due
- February 6 - 24, 2023: Experimental Safety Plan (ESP) due.
- April 7, 2023: Technical Report due
- Weekly: Check FAQs weekly for updates:
  - Task-specific FAQs: 2023 Tasks/Task FAQs
  - General FAQs: 2023 General FAQs
- All dates or task requirements are subject to change. Check FAQs for updates online.

Reference

Levri, J.A., J.W. Fisher, H.W. Jones, A.E. Drysdale, M.K. Ewert, A.J. Hanford, J.A. Hogan, J.A. Joshi, and D..A Vaccari. 2003. NASA: Advanced Life Support Equivalent System Mass Guidelines Document. NASA/TM-2003-212278. https://ntrs.nasa.gov/api/citations/20040021355/downloads/20040021355.pdf