Surviving the Lunar Night: DRPS Could Enable the Power to Explore

Project: Dynamic Radioisotope Power Systems Project

Snapshot: Dynamic Radioisotope Power Systems (DRPS) may enable lunar science payloads to survive and thrive during the harsh lunar night. New robust DRPS have been built and delivered by industry and are in the process of being tested at NASA's Glenn Research Center.

Figure 1. Engineers in the Stirling Research Laboratory at NASA's Glenn Research Center monitor Stirling Convertors on continuous test for the Dynamic Radioisotope Power Systems (DRPS) Project. Credit: NASA.

In partnership with NASA's Radioisotope Power Systems Program, the Department of Energy's Idaho National Laboratory is in the process of procuring a system-level DRPS design for a lunar demonstration. This design will then be used to develop a brassboard to reach Technology Readiness Level (TRL) 5 (component or breadboard validation in relevant environment). Subsequent steps to build, qualify, and demonstrate the system will meet Presidential Policy Directive 6 (Space Policy). This in-space demonstration of dynamic conversion will enable NASA to make the next giant leap toward implementing higher-power nuclear power and propulsion solutions.

Decades of experience have taught NASA the importance of taking small steps to accomplish big goals. This year marks the sixtieth anniversary of the first radioisotope-powered spacecraft. Radioisotope Power Systems (RPS) have been powering spacecraft to some of the darkest, dustiest, and harshest environments in the solar system. The Dynamic Radioisotope Power

System Project, led by NASA's Glenn Research Center, in Cleveland, Ohio, is taking a step closer towards a potential lunar surface demonstration of the first dynamically enhanced radioisotope power system, a DRPS.

RPS traditionally convert the heat produced by the natural decay process of plutonium-238 by using hundreds of thermoelectrics to change that heat into usable electrical power. This dense heat source is ideal for long-lived missions such as Voyagers 1 and 2, which have been operating for over 44 years—even outside of our solar system, and it is ideal for missions closer to home such as Curiosity and Perseverance, which are both exploring the dusty environment of Mars. DRPS seeks to take advantage of moving parts, or dynamic parts, to increase the efficiency of this energy conversion by as much as three to four times that of previously flown RPS. This efficiency gain could allow missions to use almost a quarter less of the heat source, which would reduce the residual heat and system mass, leaving more room for science payloads. The next step towards missions being able to realize these savings is to demonstrate the DRPS in space to raise the technology readiness level. This demonstration will build confidence in the system, decrease risk for long-duration missions, and act as a pathfinder for future fission systems that will enable NASA's Artemis Lunar Exploration program, as it also requires dynamic heat conversion technologies.

The DRPS Project has gathered data from electrically heated dynamic convertors of various designs, which have collectively operated over a million hours in the Stirling Research Laboratory at NASA Glenn. Three of these convertors have individually surpassed the 14-year mission design life requirement, increasing confidence in the technology. All these convertors use a thermodynamic cycle called a Stirling cycle, named after Reverend Dr. Robert Stirling, a Scottish clergyman who invented the Stirling heat engine.

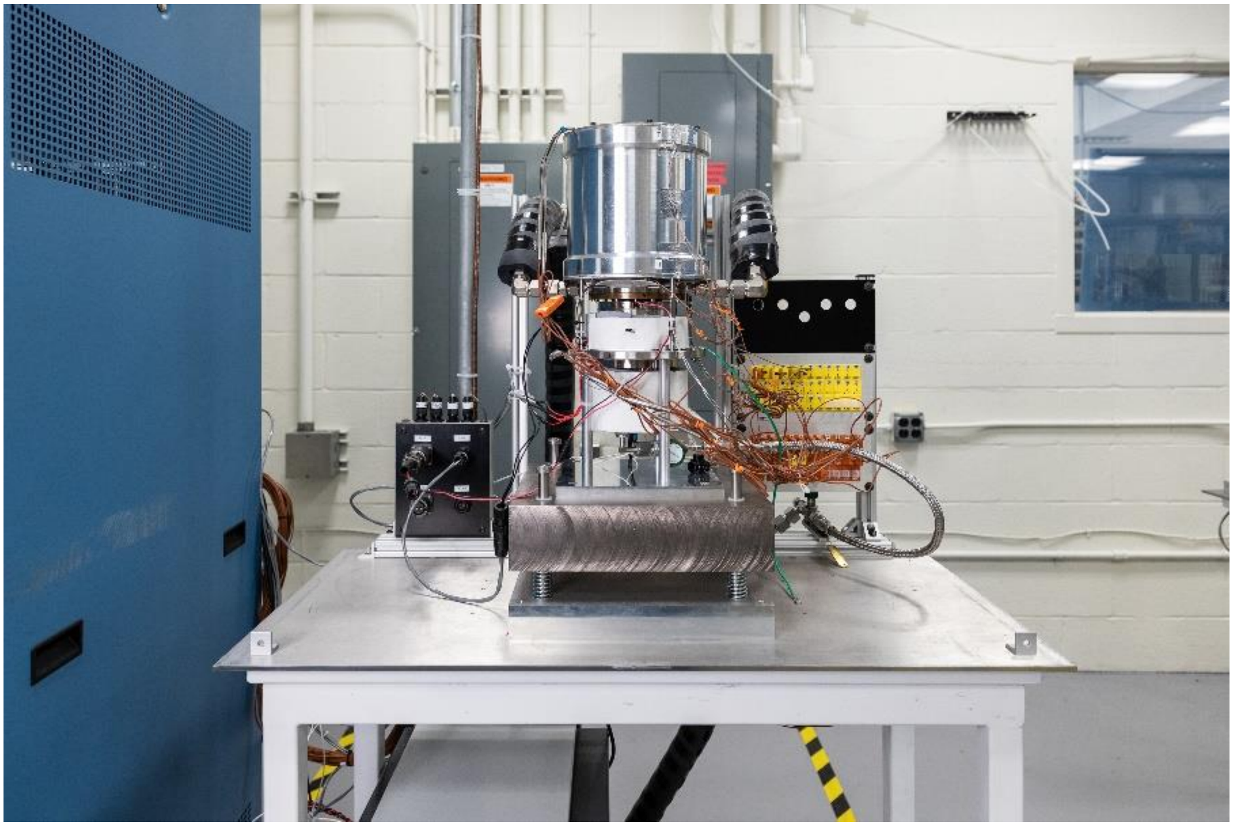


Figure 2. Characterization testing of the Sunpower Robust Stirling Convertor (SRSC) #1 in the Stirling Research Laboratory at NASA's Glenn Research Center. Credit: NASA.

The RPS investment in Stirling convertors also enabled the successful demonstration of the Kilopower Reactor Using Stirling Technology (KRUSTY) experiment in 2018. Further advancement in dynamic-based energy conversion technology has significant potential to advance space nuclear power and propulsion systems by giant leaps, increasing the power level potential into the range required for human exploration by combining this technology with fission systems.

As NASA works towards the goal of returning humans to the surface of the Moon, the DRPS Project has been developing systems in partnership with the Department of Energy (DOE). Currently, NASA Glenn holds three separate contracts to design and test dynamic convertors aimed at raising the technology readiness, while improving robustness and reliability. These technologies are being shared with industry as possible conversion technologies that can be used in a generator that would produce between 200-500 watts, depending on the system design and technology chosen. Two of the technologies are Stirling based convertors (one developed by American Semiconductor, Inc. with Teledyne Energy Systems; and the other by Sunpower, Inc. with Aerojet Rocketdyne) that can trace their roots back to the convertors that have demonstrated over 14 years of issue-free operation at NASA Glenn. The third technology uses a Turbo-

Brayton convertor (developed by Creare, LLC. with Aerojet Rocketdyne). All these dynamic convertors will undergo independent validation and verification testing at NASA Glenn. Testing of the Sunpower, Inc. convertor has already begun.

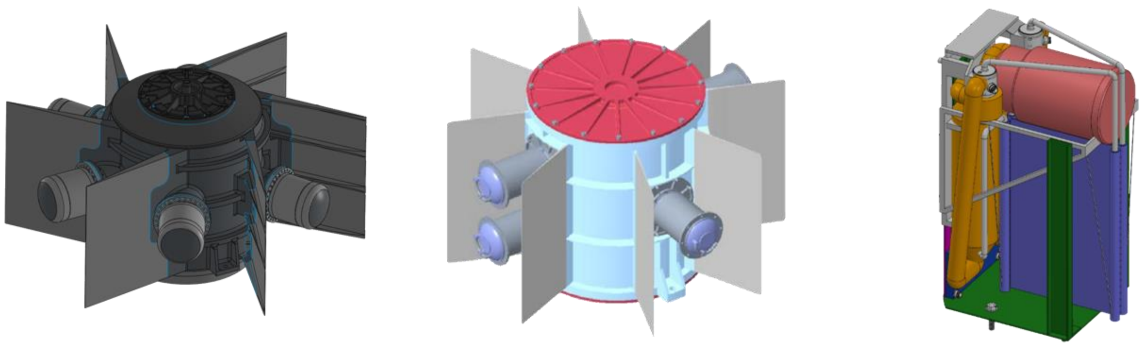


Figure 3. Conceptual Designs for DRPS. Credit (left to right): American Semiconductor, Inc. with Teledyne Energy Systems; Sunpower, Inc. with Aerojet Rocketdyne; Creare, LLC. with Aerojet Rocketdyne.

The DOE, working with NASA, has released a request for proposals by the Idaho National Laboratory for a contract to develop a DRPS design for a lunar demonstration mission. Follow-on contracts would then build and test a brassboard system to reach TRL 5 as a stepping-stone toward building a potential flight unit in the late 2020s. The contract is expected to be awarded by the end of 2021.

A lunar demonstration mission could be the first opportunity for a DRPS to be used in spaceflight. The use of DRPS in a lunar-landed payload would enable a mission to survive and operate productively during the frigidly cold, two-week lunar nights or in permanently shadowed craters near the Moon's poles, where water ice is most likely. A DRPS is also not required to follow the Sun for power generation. Utilizing technological advances in DRPS and potentially new partnership opportunities, including public-private partnerships that leverage commercial investments to further NASA's science objectives, will put NASA one step closer to making the next giant leap in space exploration.

Project Lead: J. Mark Hickman/Project Manager, Dynamic Radioisotope Power Systems Project, NASA Glenn Research Center

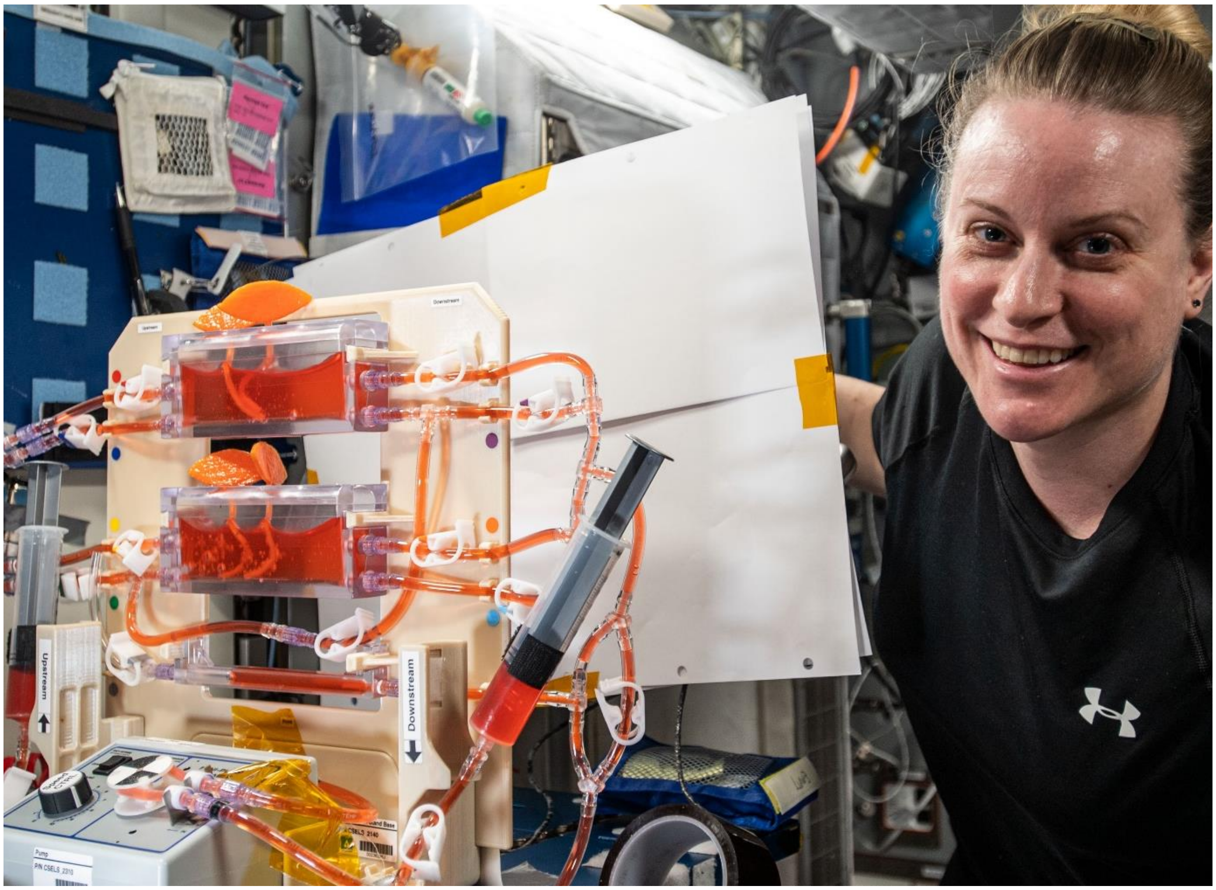
Sponsoring Organization(s): Planetary Science Division's Radioisotope Power Systems Program

Key terms: Radioisotope power systems, RPS, dynamic radioisotope power systems, DRPS, spacecraft power, Stirling convertor, Pu-238, Turbo Brayton convertor, lunar demonstration

Q: How Do You Water Plants in Space?
A: Omni-Gravitational Hydroponics

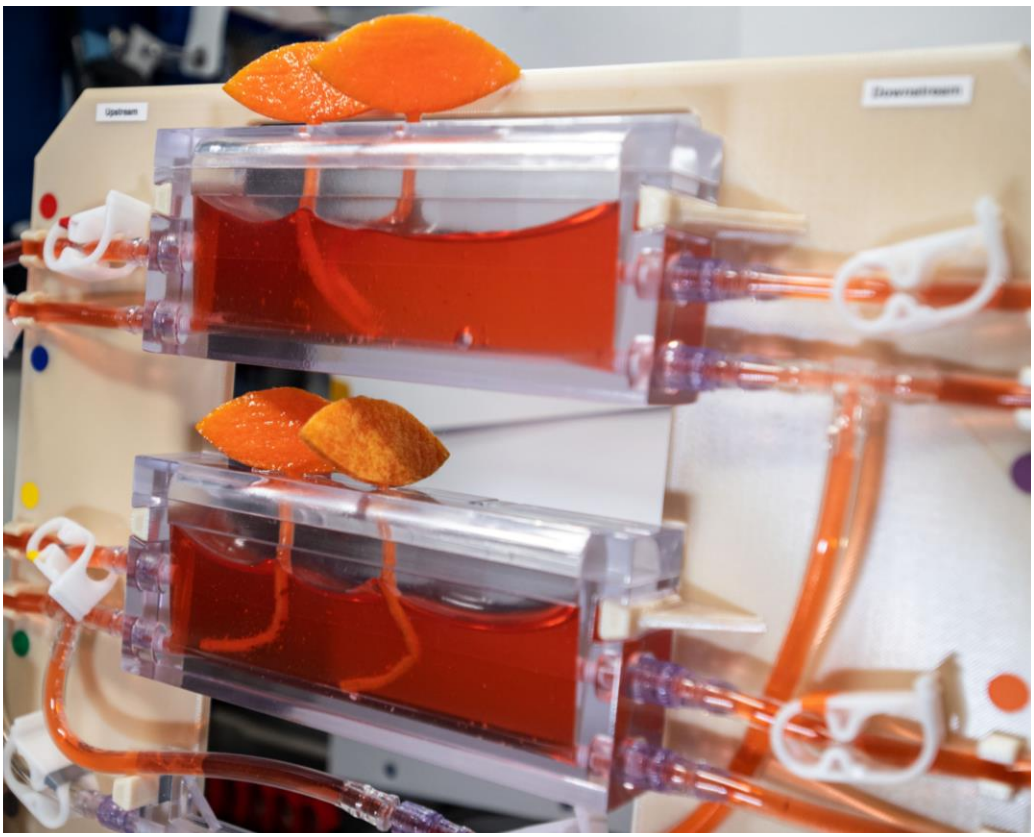
Project: Plant Water Management (PWM)

Snapshot: NASA is demonstrating that even without the help of gravity, hydroponic plant watering methods can enable plant habitats aboard crewed or robotic space missions.



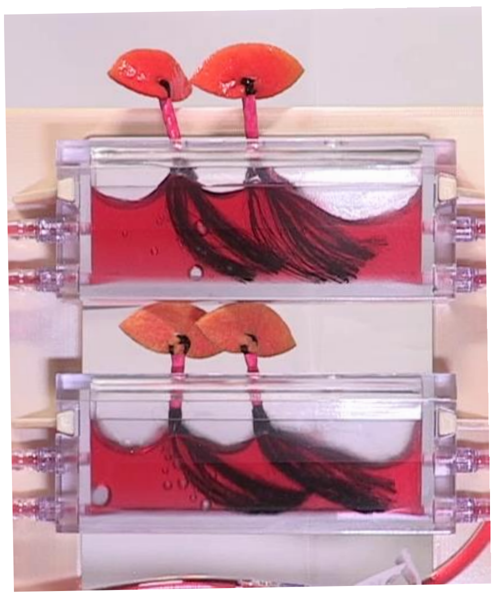
U.S. Astronaut Kate Rubins poses with PWM after nearly doubling the science returns of the ISS experiment by drawing on her wealth of wet lab operations and handling experience—on Earth and in space.

On Earth, plants draw water upwards through the roots against gravity, via capillary action, which orients the plant and enables display of its canopy (foliage and branches) for optimal photosynthesis and transpiration. The plant grows above the nutrient-rich soil as the water recedes into the soil, and oxygen from the air between the soil particles diffuses into root hair, maintaining a balance of oxygenation in the water and a dry stem. Hydroponic watering systems on Earth achieve a similar result without the soil by providing a continuous flow of aerated nutrient-rich water, which allows the plant to take up only what it needs; gravity again assures growth direction and a dry stem. Providing water to plants at the varied rates they require is difficult without gravity—which is exactly what is required of plant watering systems aboard spacecraft. Of the many methods pursued by NASA, hydroponics offers key performance advantages: low system mass, natural aeration, simplicity, and potential for automation. But how can hydroponics channels work in space without gravity to define an “up” or “down” or a “top” or “bottom?”



Parallel hydroponic channel flow on the International Space Station with felt plant root models: flow is left to right across the bottom of the channel—though in low-gravity environments there is no bottom; the bottom in this case is created by capillary forces arising from the unique channel shape (Image courtesy K. Rubins/NASA).

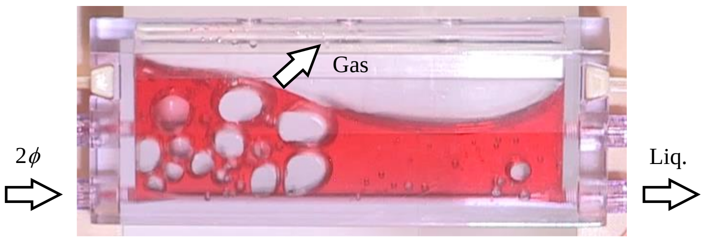
NASA has initiated a series of experiments to test capillary hydroponics onboard the International Space Station (ISS). These Plant Water Management (PWM) experiments seek to exploit the combined effects of surface tension, wetting, and hydroponic channel geometry to ensure proper water flow in space to mimic the role of gravity on Earth. Terrestrial hydroponic systems work so well, are so simple, have few failure modes, and require no media such as soil. But can we design a system in space that can replicate such characteristics? Specifically, how can we assure that the nutrient-rich water will flow safely along the "bottom" of hydroponics channels in a low-gravity environment?



Microgravity hydroponics demonstration of parallel channel flow with 2 medium-weave plant root models (flow is left to right).

The PWM hardware consists of a variable-speed metering pump, tubing, assorted valves, syringes, and several sets of capillary fluidic hydroponics channels and tubing harnesses. This setup enables a wide range of parameters to be tested—e.g., gas and liquid flow rates, fill levels, inlet/outlet configurations, bubble separation methods, and plant types, number, and order. Most of the equipment shipped to the ISS consists of 3-D printed flight-certified materials. The crew assembles the various system configurations on a workbench in the open cabin of the ISS and then executes the experiments, including routine communication with the PWM research team on the ground. All of the quantitative data is collected via a single high-definition video camera.

The PWM hardware and procedures are designed to incrementally test the system's capabilities including priming, single-channel operation, parallel-channel operation, reverse flow, serial flow, limits of operation, stability during perturbations, start-up, shut-down, and myriad plant-insertion, saturation, stable flow, and plant-removal steps.



Demonstration of passive phase separation for poorly wetting aerating two-phase (inlet at left) flow within an open 15cm-long hydroponics channel on ISS.

With each successful demonstration, the low-gravity hydroponics plumbing approach increases its Technology Readiness Level (TRL) and will eventually be used in demonstrations with actual plants, which will hopefully be performed in connection with plant habitats already on ISS (i.e., the Advanced Plant Habitat). PWM experiments currently underway on ISS focus on passive liquid delivery, fill level maintenance, serial operation, passive steady aeration, and more. Designs are in work for follow-on demonstrations targeting specific crop types, automation methods, and channel deployment architecture.

Project Lead: Dr. Mark Weislogel, Portland State University

Sponsoring Organization(s): Biological and Physical Sciences Division

Key terms: BPS, microgravity fluid physics, capillary fluidics, parallel flows, surface tension, capillary hydroponics, plant habitats