NASA SBIR 2021 Phase I Solicitation

S3.02 Dynamic Power Conversion

Lead Center: GRC

Scope Title:

Dynamic Power Conversion

Scope Description:

NASA is developing dynamic radioisotope power systems (DRPSs) for unmanned robotic missions to the MoonÂ and other solar system bodies of interest. This technology directly aligns with the Science Mission Directorate (SMD) strategic technology investment plan for space power and energy storage and could be infused into a highly efficient RPS for missions to dark, dusty, or distant destinations where solar power is not practical. Current work in DRPSsÂ is focused on novel Stirling, Brayton, or Rankine convertors that would be integrated with one or more 250-W_{th}Â general-purpose heat source (GPHS) modules or 1-W_{th}Â lightweight radioisotope heater unit (RHU) to provide high thermal-to-electric efficiency, low mass, long life, and high reliability for planetary spacecraft, landers, and rovers. Heat is transferred from the radioisotope heat source assembly to the power convertor hot end using conductive or radiative coupling. Power convertor hot-end temperatures would generally range from 300 to 500 Â°C for RHU applications and 500 to 800 Â°C for GPHS applications. Waste heat is removed from the cold end of the power convertor at temperatures ranging from 20 to 175 Â°C, depending on the application, using conductive coupling to radiator panels. The NASA projects target power systems able to produce a range of electrical power output levels based on the available form factors of space-rated fuel sources. These include a very low range of 0.5 to 2.0 W_eÂ that would utilize one or more RHU, a moderateÂ range of 40 to 70 W_eÂ that would utilize a single GPHS Step-2 module, and a high range of 100 to 500 W_eÂ that would utilize multiple GPHS Step-2 modules. For these power ranges, one or more power convertors could be used to improve overall system reliability. The current solicitation is focused on innovations that enable efficient and robust power conversion systems. Areas of interest include:

1. Robust, efficient, highly reliable, and long-life thermal-to-electric dynamic power convertors that would be used to populate a generator of a prescribed electric power output ranges.
2. Electronic controllers applicable to Stirling, Brayton, or Rankine power convertors.Â Â Â
3. Multilayered metal insulation (MLMI) for minimizing environmental heat losses and maximizing heat transfer from the radioisotope heat source assembly to the power convertor.
4. Advanced dynamic power conversion components and RPS integration

components, including efficient alternators able to survive extended exposure to 200 Â°C, robust high-temperature-tolerant Stirling regenerators, robust highly effective recuperators, integrated heat pipes, and radiators that improve system performance, and improveÂ the margin, reliability, and fault tolerance for existing components.

Expected TRL or TRL Range at completion of the Project:Â 1 to 5Â
Primary Technology Taxonomy:Â
Level 1: TX 03 Aerospace Power and Energy StorageÂ
Level 2: TX 03.1 Power Generation and Energy Conservation**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:

Phase I deliverables: results of a feasibility study and analysis, as described in a final report.

Phase II deliverables: prototype hardware that has demonstrated basic functionality in a laboratory environment, the appropriate research and analysis used to develop the hardware, and maturation options for flight designs.

State of the Art and Critical Gaps:

Radioisotope power systems are critical for long-duration NASA missions in dark, dusty, or harsh environments. Thermoelectric systems have been used on the very successful RPSs flown in the past, but are limited in efficiency. Dynamic thermal energy conversion provides significantly higher efficiency, and through proper engineering of the noncontact moving components, can eliminate wear mechanisms and provide long life. AlthoughÂ high-efficiency performance of dynamic power convertors has been proven, reliable and robust systems tolerant of off-nominal operation areÂ needed. In addition to convertors appropriate for GPHSÂ RPSs, advances in much smaller and lower power dynamic power conversion systems are sought that can utilize RHUsÂ for applications such as distributed sensor systems, small spacecraft, and other systems that take advantage of lower power electronics for the exploration of surface phenomenon on icy moons and other bodies of interest.Â AlthoughÂ the power convertor advances are essential, to develop reliable and robust systems for future flightÂ advances in convertor components as well as RPS integration components are also needed. These would include efficient alternators able to survive 200 Â°C, robust high-temperature-tolerant regenerators, robust high-efficiency recuperators, heat pipes, radiators, and controllers applicable to Stirling flexure-bearing, Stirling gas-bearing, or Brayton convertors.Â

Relevance / Science Traceability:

This technology directly aligns with the Science Mission Directorate - Planetary Science Division for space power and energy storage. Investments in more mature technologies through the Radioisotope Power System Program is ongoing. This SBIR subtopic scope provides a lower TRL technology pipeline for advances in this important power capability that improves performance, reliability, and robustness.

References:

- Radioisotope Power Systems (RPS):Â https://rps.nasa.gov/about-rps/overview/
- Oriti, Salvatore:Â "Dynamic Power Convertor Development for Radioisotope Power Systems at NASA Glenn Research Center,"Â *AIAA Propulsion and Energy*

*(P&E)*Â 2018, AIAA 2018-4498.
- Wilson, Scott D.:Â "NASA Low Power Stirling Convertor for Small Landers, Probes, and Rovers Operating in Darkness,"Â *AIAA P&E*Â 2018, AIAA 2018-4499.
- Wong, Wayne:Â "Advanced Stirling Convertor (ASC) Technology Maturation,"Â *AIAA P&EÂ* 2015, AIAA 2015-3806.

Scope Title:

Additive Manufacturing Microfabrication of Stirling Heat Engine Regenerators

Scope Description:

In space applications where solar power is not practical, dynamic power conversion is an effective alternative.Â Of the several technologies used for dynamic power conversion, free-piston Stirling heat engines, coupled with alternators, offer high thermal-to-electric conversion efficiency, low mass, and long life.Â One component of Stirling heat engines that contributes to their excellent efficiency is the regenerator, which acts as a heat exchanger/storage for the working fluid as it passes from the heat acceptor to the rejector and again as it returns to the acceptor to repeat the cycle.Â The current state of the art in the construction of regenerators results in a cylindrical annulus made up of heat- and corrosion-resistant, short metallic fibers in diameters of 20 toÂ 40 Âµm, packed to form an annulus with a porosity of 80% toÂ 90% (solid fraction 10% toÂ 20%), and sintered to achieve structural stability.Â

In some instances, these random fiber regenerators have released small particle debris due to less-than-complete sintering of the fiber matrix, presenting a risk of interference in the very small running clearance gaps of the displacer and power pistons, and potentially negatively affecting the performance and robustness of the heat engine.Â NASA has engaged in initial studies to determine the feasibility of producing continuous regenerator matrices through additive manufacturing (AM), andÂ while these studies show promise, it has been determined that limitations of selective laser melting in the minimum achievable feature size and spacing between features prevents realization of performance goals.Â Sought are advances in AM microfabrication that demonstrate:

1. ApplicabilityÂ to high-temperature, corrosion-resistant metal alloys (Inconel, FeCrAlY, etc.).
2. CapabilityÂ of creating ligaments in diameters as small as 20 Âµm, with spacing between ligaments as small as 100 Âµm.
3. CapabilityÂ of producing cylindrical annuli on the order of 5.5 cm O.D. andÂ 4.0 cm I.D. in axial lengths of up to 5 cm.Â Axial length may be achieved by stacking multiple components of shorter lengths.
4. ReasonableÂ build time to support on-demand production.
5. AbilityÂ to create regenerator matrices that are stable and robust in the anticipated vibro-acoustic environments associated with space missions (launch, pyroshock, entry/descent/landing, etc.).

Expected TRL or TRL Range at completion of the Project:Â 1 to 4Â
Primary Technology Taxonomy:Â
Level 1: TX 03 Aerospace Power and Energy StorageÂ
Level 2: TX 03.1 Power Generation and Energy Conservation**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

- Hardware

Desired Deliverables Description:

Phase I deliverables: results of a feasibility study and analysis, as described in a final report.

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Phase II deliverables: prototype hardware that has demonstrated basic functionality in a laboratory environment, the appropriate research and analysis used to develop the hardware, and maturation options .

State of the Art and Critical Gaps:

Radioisotope power Systems (RPS) are critical for long duration NASA missions to destinations sufficiently far from the Sun that solar power is impractical, and for missions to permanently shadowed areas of planetary bodies and their moons.Â Thermoelectric power systems (RTG) have enjoyed much success in past missions, but their efficiency is limited.Â Dynamic RPS offer significantly higher efficiency, resulting in lower system mass and reduced radioisotope inventory for a given power output.Â Advances in microfabrication of regenerators are needed for reduction of risk associated with stability of the regenerator matrix and improvements in reliability and robustness to support long mission durations.

Relevance / Science Traceability:

The technology described here aligns with the Science Mission Directorate Planetary Science Division (SMD/PSD) requirements for space power and energy storage and provides a low-TRL pathway for technologies that may contribute to a reduction of risk and improvements in reliability and robustness of Stirling heat engines in space-power applications.

References:

- Ibrahim, et al:Â â€œA Microfabricated Segmented-Involute-Foil Regenerator for Enhancing Reliability and Performance of Stirling Engines,â€Â NASA Contractor Report 2007-215006, 2007.
- Ibrahim, M.B. andÂ Tew, R.C.:Â *Stirling Convertor Regenerators*, CRC Press, Boca Raton, FL, 2017.