

High Efficiency Stirling Power Conversion for Robotic Space Exploration

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STIRLING POWER CONVERSION DESIGNS HAVE ACHIEVED HIGH TRL

- Sunpower Robust Stirling Convertor (SRSC) has passed key environmental tests demonstrating performance/robustness at TRL 5
 - Margin to survive Moon and Mars temperature extremes
 - Demonstrated non-contacting bearings survive external loading from qual-level random vibration and high-g centrifuge testing
 - Survival of electrical load loss verified during production testing
- Multiple convertors have operated over 17 years, controller engineering model operated over 14 years
- Reliability of convertors has been demonstrated by analysis and testing

FLIGHT DEMONSTRATION NEEDED FOR TRL ADVANCEMENT



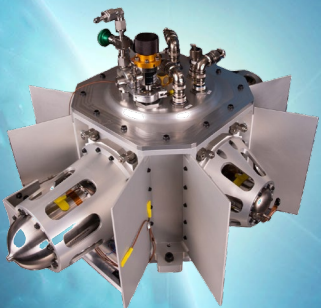
Sunpower Robust Stirling Convertor (SRSC)

Convertor Parameters	Value
Convertor Power Output	Demonstrated 88 W _e
Design Life (includes 3 yrs of storage)	17 years
Convertor Efficiency	Demonstrated 31%
Convertor Mass (SRSC)	3.6 kg
Robustness	Loss of Load Tolerance

HIGH EFFICIENCY STIRLING GENERATORS OFFER NEW FUEL ECONOMY

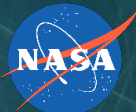
- High efficiency (> 20%) reduces required amount of fuel and corresponding emitted radiation
- High reliability is achieved using redundant convertors and controllers
- NASA's Stirling Generator Testbed allows for demonstration of critical interfaces and fault tolerance scenarios
 - Demonstrated 17% efficiency in unoptimized design/test conditions using radiantly-coupled Stirlings to central heat source stack
 - Demonstrated stable operation of housing with four convertors operating
 - Demonstrated heat rejected to environment using fins

STIRLING GENERATOR DESIGNS CAN BE ADAPTED TO VARIETY OF MISSIONS



Stirling RPS Generator Testbed, NASA GRC

Generator Parameters	Value
Generator Power Output	100 - 500 W _e
Design Life (includes 3 yrs of storage)	17 years
Generator Efficiency	> 20%
Target Specific Power	3 W _e /kg
Robustness	Single fault tolerant



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STIRLING CONVERTORS SELECTED FOR COMMERCIAL RPS DEVELOPMENT

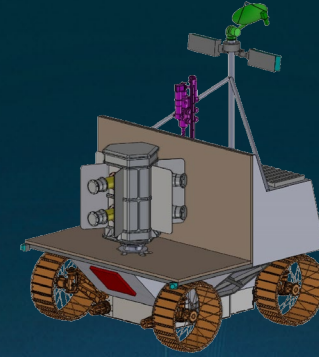
- Commercial development of Stirling RPS designs in progress on NASA's Harmonia and AFRL's JETSON using high TRL SRSC
- Stirling power conversion and high efficiency applicable for RPS with commercial isotope heat sources
- NASA's Tipping Point selected Zeno Power Systems to develop an americium-241 (Am-241) radioisotope Stirling generator (RSG) for lunar surface missions
- COMPASS study completed for Viper-class rover concept powered by Americium-based Stirling RPS

STIRLING RPS ENABLING SURVIVE & THRIVE THE LUNAR NIGHT

STIRLING CONVERTORS DEMONSTRATED FOR FISSION SURFACE POWER

- 100 W_e Stirling convertors used in Kilopower KRUSTY reactor demonstration
- 1 kW_e Stirling convertors demonstrated in tech dev for 40 kW_e Technology Demonstration Unit (TDU)
- 12 kW_e Stirling convertor used in the TDU thermal-vac test
- 1 kW convertors delivered to DOE's ARPA-E GENSETS project for Combined Heat & Power application

STIRLING TECHNOLOGY AVAILABLE NOW FOR FLIGHT DEVELOPMENT

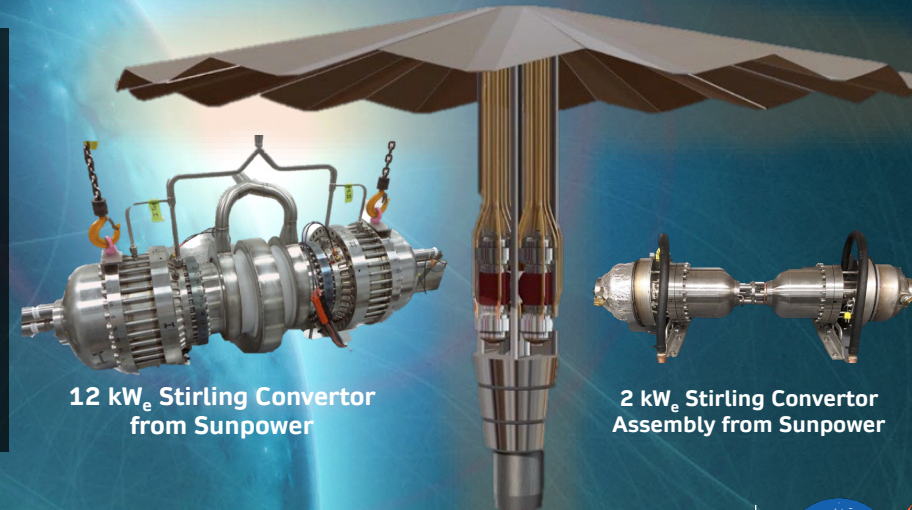


Viper-class rover concept
powered by 203 W_e
Americium-241 Stirling RPS



Zeno Power's Rover Concept
Powered by a Radioisotope
Stirling Generator

40 kW Fission Surface Power (FSP)
Heat Pipe Cooled Stirling Concept



12 kW_e Stirling Converter
from Sunpower

2 kW_e Stirling Converter
Assembly from Sunpower