Pathfinding the Advanced Stirling Convertor Flight Design with the ASC-E3. W. A. Wong[1], K. Wilson[2], Eddie Smith[3], and J. Collins[4], [1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135, [1]wayne.a.wong@nasa.gov, [2, 3, 4]Sunpower, Inc., 1055 E. State Street - Suite D, Athens, Ohio 45701-2627, [2]Wilson@sunpower.com, [3]smith@sunpower.com, [4]collins@sunpower.com

Introduction: The Advanced Stirling Convertor (ASC) was initially developed by Sunpower, Inc. under contract to NASA Glenn Research Center (GRC) as a technology development project. The ASC technology was intended to fulfill NASA's need for high efficiency power conversion systems for future Radioisotope Power Systems (RPS). The high efficiency system reduces fuel requirements lowering system mass and makes best use of the small plutonium inventory in the U.S. for fueling NASA science missions. Early successful technology demonstrations between 2003-2005 eventually led to the expansion of the project including the decision in 2006 to use the ASC technology on the Advanced Stirling Radioisotope Generator (ASRG). Sunpower has delivered 22 ASC convertors of progressively mature designs to date to GRC. Currently, Sunpower with support from GRC and Lockheed Martin Space System Company is developing the flight ASC-F in parallel with the ASC-E3 pathfinders. Sunpower will deliver four pairs of ASC-E3 convertors to GRC and they will be used for extended operation reliability assessment, independent validation and verification testing, system interaction tests, and to support LMSCC controller development. The ASRG is part of two of the three candidate missions being studied for selection for the Discovery 12 mission.

ASC Technology Evolution: The high efficiency goal and low mass of the ASC project was accomplished with the initial technology demonstration convertors (ASC-1, ASC-0, and ASC-1HS). Based on these successful performance demonstrations, NASA Headquarters provided direction to accelerate ASC technology development to transition towards flight implementation. In response, the ASC project was modified to include direct technical support from GRC, with tasks focused on reducing risk and enhancing reliability of the ASC. Additionally, the Department of Energy (DOE) and Lockheed Martin adopted the Sunpower ASC as part of the ASRG. To transition the ASC from technology development to flight, the general plan illustrated in Figure 1 was agreed to that shows the advancement of the technology with several progressive convertor designs.

Completion of the technology development and transition to flight are part of Sunpower's development contract with GRC, whereas flight hardware development and production are part of Sunpower's subcontract to the DOE/Lockheed Martin ASRG contract. Each successive build includes design and processing changes to meet newly defined requirements, improve manufacturability, or improve reliability. Sunpower and GRC developed the ASC-E and worked collaboratively with Lockheed Martin to develop the product specification requirements for the ASRG Engineering Unit (EU), including generator interfaces and preliminary flight requirements. In October 2007, two ASC-E convertors along with a spare were delivered on schedule as Government Furnished Equipment to DOE/Lockheed Martin for integration onto the ASRG EU. The ASRG EU completed a variety of system level tests at Lockheed Martin before eventual delivery to GRC where it is currently undergoing continuous extended operation.

While the ASC-E convertors represented a major advancement of the technology, the ASC required further development to prepare for flight. It was recognized that, due to evolving requirements, refinement of the design, and a need to continue to mature the quality system at Sunpower, two additional generations of ASC convertors were needed. The ASC-E2 design would be built under a new formal Quality Management System at Sunpower, and would implement several reliability-driven or flight requirements-driven design changes. The eight ASC-E2 convertors were completed and delivered to GRC in 2010 for extended operation and durability testing.

ASC-E3 Pathfinding the Flight Design: As illustrated in Figure 1, the original intent was to complete the technology development phase with ASC-E3 prior to commencement of flight production. However, the technology maturation plan has been compressed in order to support the candidate Discovery 12 mission opportunity. Sunpower has recently started fabrication of the ASC-E3 convertors for GRC, and is in parallel, developing the ASC-F convertors for Lockheed Martin's ASRG flight project. This circumstance of parallel convertor builds with the intial two pairs of ASC-E3 convertors leading the way allows for a unique opportunity to use the ASC-E3s as pathfinders for the design and process changes that are part of the ASC-F.

The intention is that the ASC-E3 and –F convertors will be built to the same design and processing documentation and the same product specification. The current plan is to phase the ASC-E3 build into an initial "developmental" set (the first two pairs), followed by a "flight-like" set (the last two pairs). This plan allows

the reduction of risk by using the initial two pairs of ASC-E3 to validate design and processing changes prior to implementation on the ASC-F, and to develop and verify the cleanliness and planetary protection procedures that may be required for flight. Meanwhile, it is expected that the flight requirements and documentation will be finalized by the time the last two pairs of ASC-E3 are produced so that these convertors will be fully representative of the flight convertors and can undergo extended operation and independent validation and verification testing at GRC.

A Joint Configuration Control Board (CCB) with membership from GRC, DOE, Lockheed Martin, and Sunpower has been formulated and has the responsibility to review a single set of Sunpower ASC design documentation to maintain configuration control for the ASC-F build and the ASC-E3 build.

ASC-E3 Production Status: After successful completion of the ASC-E3 Long Lead Production Readiness Review (PRR) held in November 2010, production of the three critical long lead components was initiated: The heater head assembly and displacer assembly produced by a subcontract team led by Refrac Systems, Inc. and the transition assembly. A second PRR for the entire ASC-E3 convertor was held in April 2011 resulting in authority to proceed for the first two ASC-E3 pathfinding pairs starting June 2011. At the time of the PRRs, not all requirements and design details were finalized for the flight design so the initial E3 convertors have proceeded with "TBR" notation on some design and process details.

Meanwhile, Sunpower was in the process of relocating to a new larger facility made necessary by the growing staff and increased production requirements for the ASRG flight project. Sunpower completed the relocation on schedule in July 2011. One of the primary drivers for the relocation is the flight cleanliness requirements that necessitate build-up and processing in a clean room environment. The plan is for the first ASC-E3 pair to pathfind the flight design and process changes as early as possible without clean room processing in order to identify potential developmental issues. The second ASC-E3 pair will then serve as the first hardware to undergoing production in the new Sunpower clean room facility.

As of December 2011, the initial long lead heater head assemblies, displacer assemblies, and transition assemblies for ASC-E3 have been completed. Additionally, many other components have either been completed or are nearing completion. It is anticipated that all components for the first ASC-E3 pair will be completed by January 2012 allowing initiation of build up. ASC-E3 first operation is expected by February 2012 with delivery to GRC in the summer.

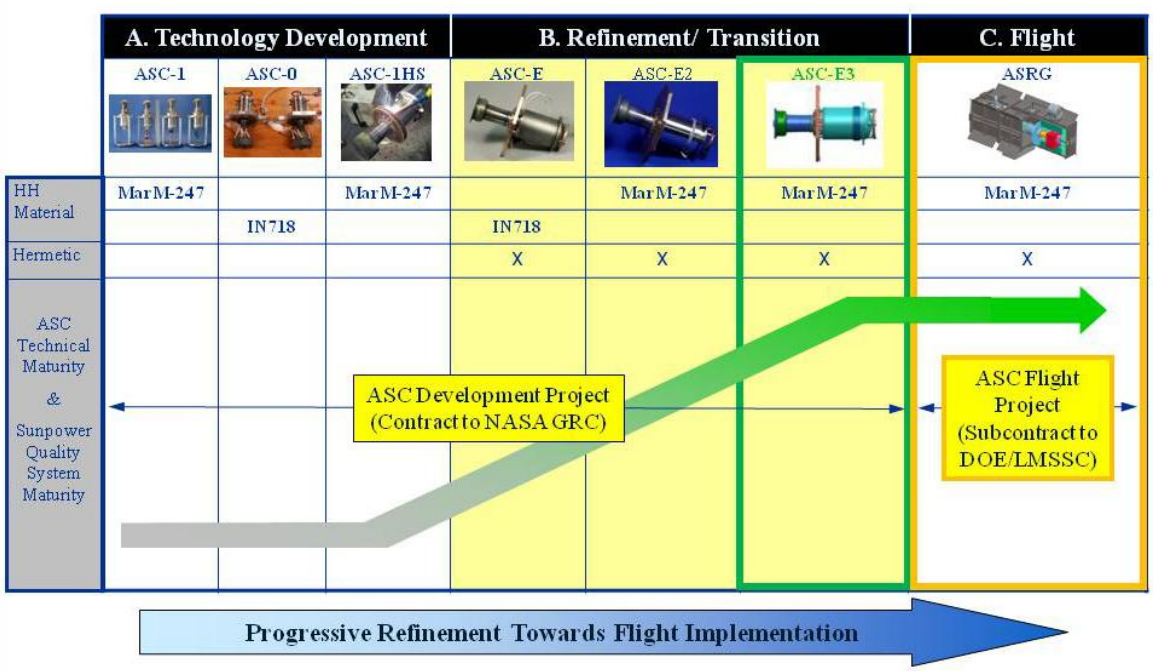

FIGURE 1. Sunpower ASC Convertor Evolution From Technology Development to Flight.