AIAA 2017-5102
AIAA SPACE Forum
12 - 14 Sep 2017, Orlando, FL
AIAA SPACE and Astronautics Forum and Exposition

Progress and Plans for Sierra Nevada Corporation's NextSTEP-2 Deep Space Habitat

Jeff Valania[1]
Sierra Nevada Corporation, Louisville, CO 80027

Sierra Nevada Corporation (SNC) is developing an architecture and full-scale ground prototype for a deep space habitat system under NASA's Next Space Technologies for Exploration Partnerships-2 (NextSTEP-2) Habitat Systems contract. SNC's deep space habitat architecture is a modular, extendable, and highly capable habitat system. SNC's concept of operations (CONOPS) provides an evolutionary approach to both the building blocks and overall system architecture that is consistent with NASA's timeline and vision for developing a cislunar Deep Space Gateway (DSG). During the NextSTEP-2 program, SNC will study and refine the proposed architecture and will develop a full-scale ground prototype to confirm the proof of concept and reduce key technical risks. SNC is pursuing commercial applications for technologies developed on NextSTEP-2, including an on-orbit servicing platform and a commercial low Earth Orbit (LEO) space station for microgravity research, in-space manufacturing, and future human space activities.

Nomenclature

CM	=	Cargo Module
CONOPS	=	Concept of Operations
CRS2	=	Commercial Resupply Services 2
DSG	=	Deep Space Gateway
ECLSS	=	Environmental Control and Life Support Systems
ELCM	=	Extended Logistics Control Module
EM	=	Exploration Mission
EP	=	Electric Propulsion
EVA	=	Extra-vehicular Activities
GN&C	=	Guidance, Navigation, and Control
ISS	=	International Space Station
JSC	=	Johnson Space Center
LaRC	=	Langley Research Center
LCM	=	Logistics and Control Module
LEO	=	Low Earth Orbit
LIFE	=	Large Inflatable Fabric Environment
MASH	=	Minimalistic Airlock with Soft-goods Hatch
MEO	=	Medium Earth Orbit
NextSTEP	=	Next Space Technologies for Exploration Partnerships-2
ORBITEC	=	Orbital Technologies Corporation
PPE	=	Power and Propulsion Element
RTP	=	Resilient Tunnel Plug
SEP	=	Solar Electric Propulsion
SEPM	=	Solar Electric Propulsion Module
SLS	=	Space Launch System
SNC	=	Sierra Nevada Corporation
TRL	=	Technology Readiness Level

[1] Principal Systems Engineer, Space Systems, 1722 Boxelder Street, Louisville, CO 80027, AIAA Senior Member.

I. Introduction

SIERRA Nevada Corporation (SNC) was awarded a NASA Next Space Technologies for Exploration Partnerships-2 (NextSTEP-2) Habitat Systems contract to develop an architecture and ground prototype for a deep space habitat system that supports NASA's vision for a cislunar orbiting Deep Space Gateway (DSG). SNC assembled a national team for the NextSTEP-2 design that combines SNC's systems integration capability from a long heritage of flight-proven satellites and work on NASA's Commercial Resupply Services 2 (CRS2) program. The core team consists of SNC Space Systems, Aerojet Rocketdyne, ILC Dover and NASA Langley Research Center (LaRC). This group brings together industry leaders in environmental control and life support systems (ECLSS), solar electric propulsion (SEP), inflatable soft goods and radiation analysis, critical for developing a viable deep space habitat.

II. Architecture Overview

SNC's deep space habitat architecture is a modular, extendable, and highly capable habitat system (Fig. 1). The concept uses a building-block approach to develop a large in-space outpost that can be positioned in a variety of orbits and, once assembled, can move to different orbits thus enabling a variety of deep space exploration missions.

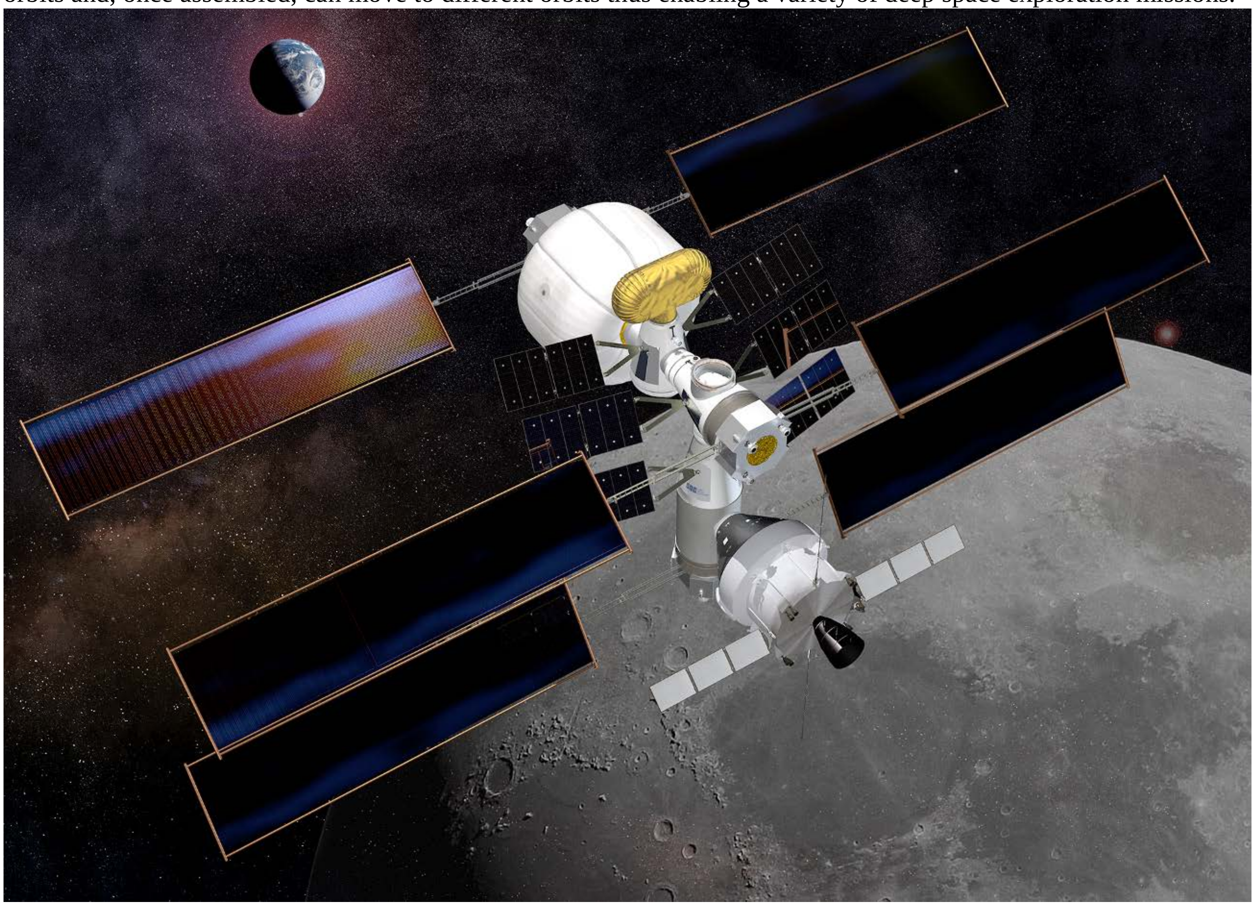

Figure 1. SNC Deep Space Habitat. *A modular and flexible system designed to meet NASA's needs for an enduring deep space habitat.*

The modular building blocks, shown in Fig. 2, include:

- Logistics and Control Module (LCM) used to house the free-flying and life-support components and serve as assembly nodes.
- Minimalistic Airlock with Soft-goods Hatch (MASH) used for extra-vehicular activities (EVA) that enable installation and servicing of orbital replacement units (ORU).
- Solar Electric Propulsion Module (SEPM) used for transporting the various building blocks to a location in space for assembly of the habitat and for providing additional power generation to support the overall system when not in transporting mode.

- Large Inflatable Fabric Environment (LIFE), which provides a large living and experiment processing area for the crew.
- Extended Logistics Control Module (ELCM) used to provide supplies and ORUs needed for long-duration crewed missions on an enduring cislunar platform.

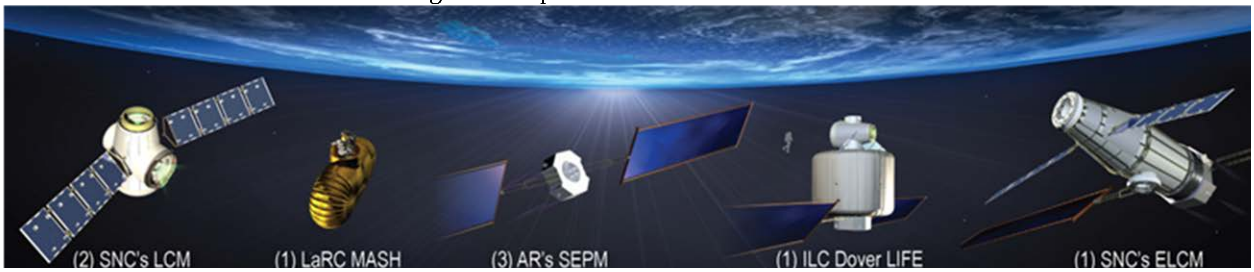

Figure 2. SNC's CONOPS for the NextSTEP Habitat System Buildup. *SNC's CONOPS relies on incremental evolution of each system and subsystem to advance the final architecture.*

Scalable ECLSS components are housed in both the LCM and LIFE elements to sustain human life. Free-flying components such as avionics, guidance, navigation and control (GN&C), and power distribution are housed in either the LCM or as a modular addition to the SEPM. All of these elements can be combined in multiple ways and offer the flexibility to create a specific operational configuration and allow for future mission expansion. The final system accommodates docking of Orion for extended crewed missions.

NASA has identified four essential architecture elements for developing the DSG: power and propulsion element (PPE), habitation element, logistics element, and airlock element. As shown in Table 1, SNC's building blocks map directly to the desired capabilities for each of the essential DSG elements. SNC's modular approach to building the cislunar habitat offer flexibility to expand or modify the DSG design if program requirements change.

NASA has outlined a plan to launch each element of the DSG directly to cislunar orbit using the co-manifested payload capability of the Space Launch System (SLS). While SNC's architecture elements could be co-manifested on SLS, SNC has developed an alternative concept of operations (CONOPS) that also satisfies each phase's objectives while minimizing hardware and launch costs (Fig.2). SNC's CONOPS provides an evolutionary approach to both the building blocks and overall system architecture that is consistent with NASA's timeline and vision for developing the DSG.

SNC employs the three operational phases outlined by NASA in the NextSTEP program to accomplish the buildup and validation of the final long duration cislunar DSG. The first phase begins with a co-manifested launch with CRS2 and testing of LCM, ECLSS, SEP, MASH, and small inflatable habitat elements of the system at the International Space Station (ISS) (Fig. 3). Testing is performed at ISS to reduce key system risks and demonstrate important features for human habitation, including ECLSS, radiation protection, and EVA capabilities. Following ISS testing, the LCM detaches from ISS, raises orbit and mates with an additional LCM/SEPM subassembly. An orbit raise is conducted again to cislunar orbit using electric propulsion (EP). The combination of the LCMs and SEPM provide a power and propulsion capability that meets the requirements for the DSG Power and Propulsion Element (PPE).

In the next phase, the LIFE and a SEPM are launched into a medium Earth orbit (MEO). EP is used to complete the transfer of these habitat elements to cislunar orbit. The addition of the LIFE/SEPM to the initial architecture elements provides the habitation capability required for the DSG to support crewed occupancy for 30-60 days.

Table 1. SNC Approach to DSG Build-up. SNC architecture elements outlined for NextSTEP-2 support the build-up of NASA's DSG.

DSG Element	SNC	Description
Power and Propulsion Element	SEPM + LCM	Transportation, orbit maintenance, power for the overall system, communication, GN&C functions
Habitation	LIFE Habitat	Habitable volume for crew, radiation protection, ECLSS and consumables
Logistics	ELCM	ECLSS, crew equipment, ORUs, consumables, waste product management, GN&C functions and module support power for long-duration deep space missions
Airlock	MASH	Airlock for EVA

Figure 3. NextSTEP-2 Testing at ISS. *Testing of SNC's initial architecture elements at ISS reduces key system risks and demonstrate important features for human habitation, including ECLSS, radiation protection, and EVA capabilities.*

In the last operational phase, an ELCM/SEPM is launched into MEO and transferred to the existing cislunar architecture via EP. These new elements supply additional cargo, power, and EP. In this way, the ELCM/SEPM provides the logistics function necessary to maintain the DSG for long durations. The completed deep space architecture supports Orion docking and its crew for a long duration mission (1,000+ days) at the DSG. The final architecture can be moved into various cislunar orbits to support different missions, including lunar surface operations.

This CONOPS allows for incremental testing of the system at various orbits; proof of rendezvous and on-orbit assembly operations; and testing and validation of free-flying and life support systems. This efficient building-block approach also results in no waste of launched components as they are used to create the final system. The result is a modular and flexible system that can efficiently meet the desired schedule to build up the DSG.

III. NextSTEP-2 Approach

During the NextSTEP-2 program, SNC will study and refine the proposed architecture and CONOPS in detail to: 1) further assess their ability to meet the criteria for each operational phase, and 2) identify challenges or risks that should be addressed early in the program. SNC will also develop and test a full-scale ground prototype to confirm the proof-of-concept, reduce risks as early as possible, and ensure the critical subsystems seamlessly integrate together.

A. Modular Architecture Development

Individual building blocks evolved from components with a high technology readiness level (TRL) comprise the cornerstone of the design. By evolving the LCM from the CRS2 cargo module (CM), the LIFE module from ILC Dover's commercial Resilient Tunnel Plug (RTP) design and TransHab technology, and the ECLSS system from the *Dream Chaser*® spacecraft, SNC can accelerate the schedule and leverage previous investments to effectively lower overall program costs. The evolution of the individual building blocks and the overall system are shown in Fig.4.

Because of the building-block approach, the overall system can be broken down into smaller configurations capable of being launched on lower-cost commercial launch vehicles, which provides NASA with options to launch each element of the habitat system. Furthermore, because of their free-flying capabilities, these separate launched assemblies can operate autonomously and rendezvous with previously launched assemblies once in orbit.

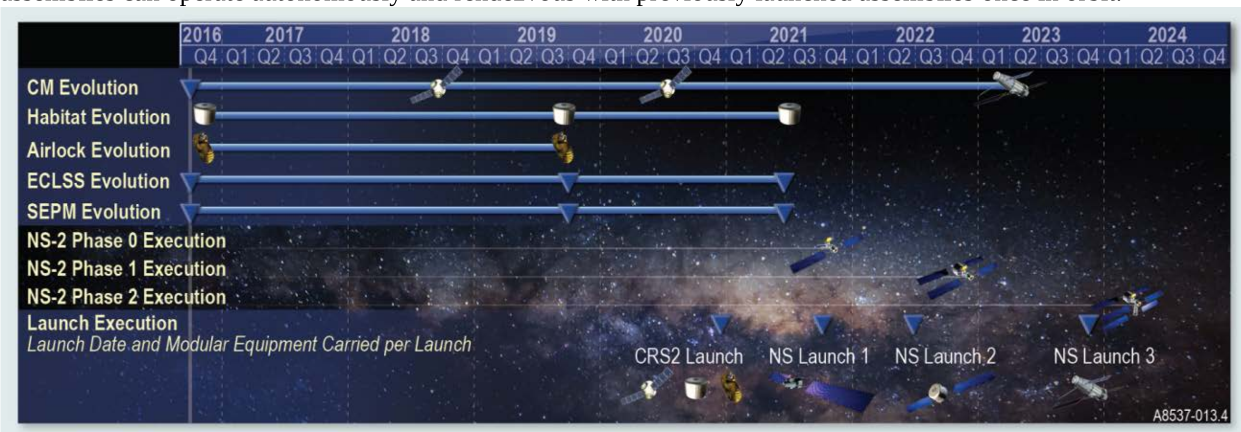

Figure 4. Architecture Evolution. *SNC leverages high TRL components and incremental evolution of the system and subsystems to efficiently meet the objectives of all mission phases.*

B. Co-Manifested Payload Concept Development

NASA has outlined a plan to launch the four elements of the DSG as co-manifested payloads on Exploration Mission (EM) flights EM-2 through EM-5. SNC's modular approach could also use co-manifested launches to reduce the overall program cost. An LCM, ELCM, LIFE module, or SEPM could all be co-manifested on SLS, assuming the 8-10 metric ton co-manifested payload capability advertised for SLS Block 1B system. As part of the CONOPS, SNC is also planning to use one of the manifested CRS2 launches that would typically include an uncrewed Dream Chaser vehicle and CM; however, for this mission, SNC replaces the CM with the LCM, which contains all of the elements to be tested at ISS.

C. Full-size Ground Prototypes and Integrated System Maturation

To prove the overall system concept and begin the risk-reduction process, SNC will build a full-scale prototype. This prototype provides the testing of basic functionality for key integrated systems, receipt of early feedback to the design team on improvements to be incorporated during follow-on execution phases and crewed experience in a large living environment. This prototype, as shown in Fig.5, consists of a full-scale LCM and inflatable LIFE, plus functional ECLSS elements to conduct airflow measurements, and component mockups to assess habitat volume accommodations and perform human factors evaluations. This integrated prototype will prove the overall concept and can be easily modified in the future to support ground-based system testing throughout the evolution of the design.

D. LIFE Fabric Test Program

The inflatable LIFE habitat provides the majority of the habitable volume for crew members in SNC's deep space habitat. As such, thorough testing of the inflatable fabric materials, as well as the overall inflatable system design, is critical to ensure successful long duration operation in cislunar space. SNC has outlined a test program to demonstrate the ability of the LIFE to meet key structural requirements for human habitation.

The SNC team will begin with fabric webbing sample testing to characterize performance of materials to be used in the inflatable habitat restraint layer. Fabric samples will be tested in various environments and following representative packaging to determine strength, knock down factors and safety factors of the fabric to be used in the inflatable restraint layer. Accelerated life tests will be conducted to characterize long-term creep performance of the fabric webbing when integrated into the LIFE habitat.

From the fabric sample test results, the SNC team will design and build three inflatable ground test articles that are one-third scale of the full-scale habitat element. The SNC team will conduct proof testing on the first of the three ground test articles. Following proof testing, the one-third scale ground test articles will be shipped to NASA Johnson Space Center (JSC) to perform burst and creep testing. This burst and creep testing will be performed by NASA JSC personnel with the support of the SNC team.

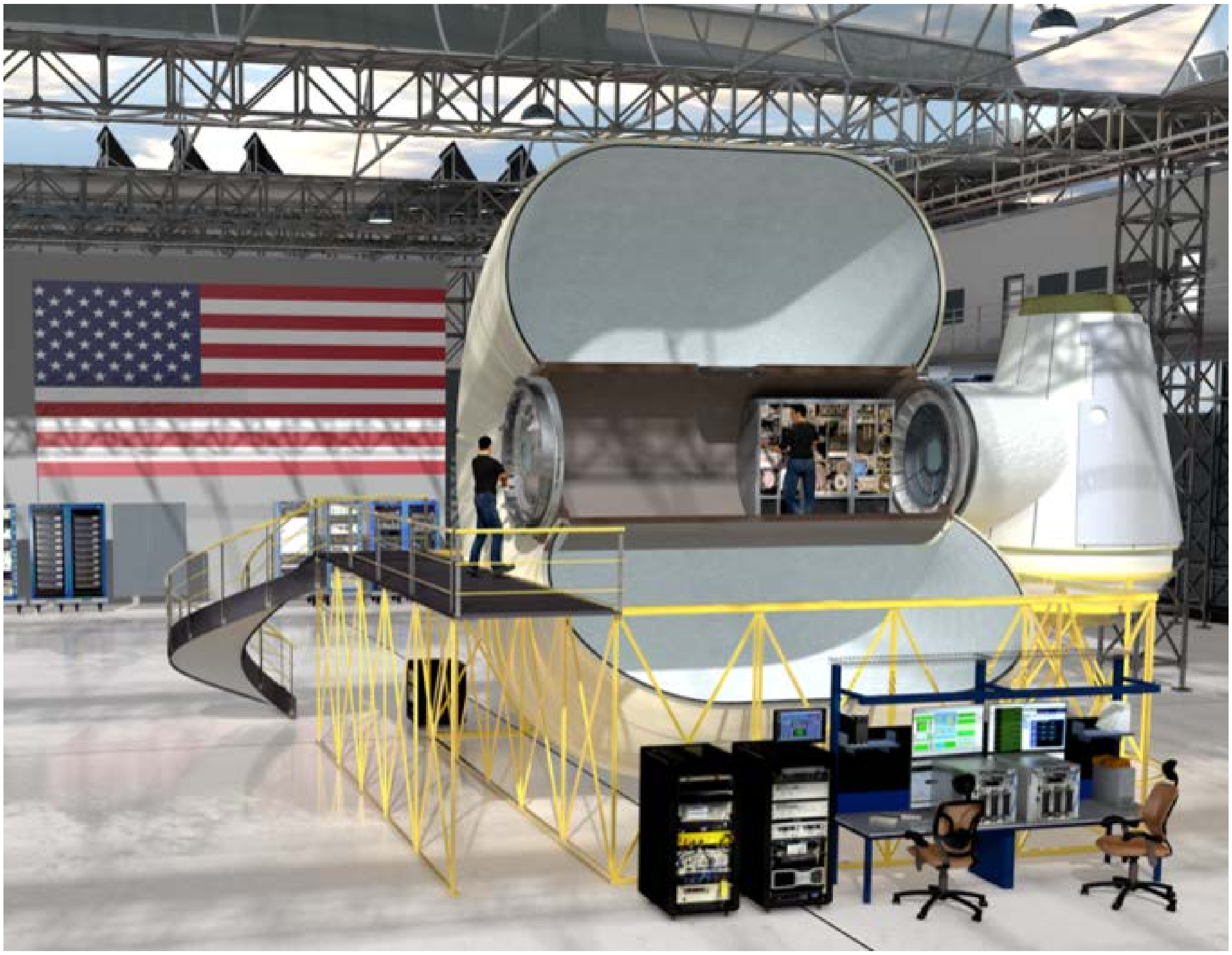

Figure 5. SNC Full-scale Ground Prototype. *Development of a full-scale ground prototype provides significant risk reduction in inflatable development and ECLSS design, and provides a test bed for human factors evaluation.*

The full-scale prototype LIFE habitat will be made of flight materials, with a design that is informed by the fabric webbing sample testing and the one-third scale article testing. Proof testing will be performed on the full-scale prototype LIFE habitat to ensure safety for its use in ground testing. Since the full-scale LIFE habitat will be made of flight materials, the future potential exists to perform real-time, long duration creep testing on this full-scale test article. This would provide extremely valuable correlation data for creep behavior models based on accelerated creep test data.

E. Commercial Low-Earth Orbit (LEO) Application Development

Technologies leveraged or developed during this program have broad commercial space applications that are already being pursued by SNC and its partners. When enhanced with robotic arms, the LCM developed under NextSTEP performs as a multi-use on-orbit servicing platform. The combination of the SEPM with either an LCM or ELCM can provide low-cost cargo transportation service between various Earth orbits, cislunar orbits and beyond. SNC's modular habitat architecture provides options to develop a low-cost LEO platform that can be tailored to offer a variety of services for microgravity research, in-space manufacturing capabilities, and human space activities.

The independently viable elements improve overall affordability of the SNC deep space habitat system, which further enables extended exploration and a wider array of commercial space activities. A multitude of commercial and government opportunities are organically derived with this technology and modular architecture approach, building upon existing or planned element capability.

IV. Conclusion

SNC and its partners have developed a concept for a deep space habitat system that is modular, extendable and capable of meeting NASA's timeline and vision for the DSG. The modular architecture can be launched as co-manifested payloads on SLS or on commercial launch vehicles, offering NASA flexibility in launch options. Under the NextSTEP-2 contract, the team will continue to refine this concept to ensure the architecture meets NASA's needs for future deep space exploration. The full-scale ground prototype being developed for NextSTEP-2 will prove the overall concept and can be easily modified in the future to support ground-based system testing throughout the evolution of the design.

SNC is evaluating several new technologies that may offer significant benefits to a deep space habitat architecture (Fig. 6). A hybrid life support system that builds on the successful VEGGIE system (developed by SNC's former subsidiary Orbital Technologies Corporation) could improve ECLSS capabilities, while also providing a radiation shelter for the crew. Inclusion of Genesis Engineering's Single Person Spacecraft into the habitat architecture could reduce EVA accommodation requirements for the habitat system, improve efficiency of external habitat maintenance operations, and reduce crew risk associated with these operations. Additive manufacturing capabilities, such as Made In Space's Additive Manufacturing Facility can be used to develop tools and replacement parts on-demand from recycled materials, reducing unnecessary cargo delivered to the habitat.

Technologies SNC develops under NextSTEP-2 are expected to support future commercial ventures, including development of an on-orbit servicing platform and a commercial LEO space station for microgravity research, in-space manufacturing, and future human space activities.

(a) Hybrid life support system (b) Single Person Spacecraft (c) Additive Manufacturing Facility

Figure 6. Technologies Under Consideration for SNC's Habitat. *SNC will evaluate the use of new technologies that could offer significant benefits to the deep space habitat.*