PARAGON®
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Mars One Habitat ECLSS (ECLSS) Conceptual Design Assessment

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Revisions

Rev	Description	Date
NC	Original DRAFT Release to initiate discussions with customer for Sections 1 through 4.	05/06/13
A	Original Release includes system description and go forward options.	05/18/15
B	Replaced Figure 4 with the correct graphic.	06/11/15

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1 Introduction

1.1 Background

Paragon has been contracted by Mars One to conduct a conceptual design of an Environmental Control and Life Support System (ECLSS) module for the Mars One Habitat and the Surface Suit System to be used by the crew while exploring and working in the external Martian environment. This document serves to compile for transmittal to the customer the emerging assessment of the Mars One Habitat ECLSS module conceptual design. This document contains a subset of the work performed to be compliant with United States International Traffic in Arms Regulations (ITAR) regulations and as defined in the original governing Technical Assistance Agreement (TAA) signed by Paragon and Mars One and approved by the United States Department of State (899900734A). During the course of this work, and before this report was transferred to Mars One, export compliance oversight shifted to the United States Department of Commerce. Per Export License D1014710 and specifically Rider 1.1, which is valid as of May 07, 2015 and expires May 31, 2019, the Habitat ECLSS is not Export Controlled.

For the equivalent work on the Mars One Surface Exploration Suit System (SESS) which is Export Controlled and governed via Export License D1014710, please refer to Mars One Surface Exploration Suit System Conceptual Design Assessment (907300008).

1.2 Scope

The scope of this conceptual design assessment is limited to the Mars One Habitat Physiochemical Environmental Control and Life Support System (ECLSS) module. Physiochemical ECLSS is emphasized as there is no bioregenerative life support functionality provided by the ECLSS module. It is understood that early adoption of bioregenerative life support (including food production) is desired by Mars One and that it will be phased in as the habitat expands. As such, any early implementation of bioregenerative life support will be performed by an independent Mars One Surface System. The conceptual design assessment also does not address leak detection, isolation, and repair or crew systems functions such as clothing, personal items, entertainment, galley and food, hygiene, exercise, medical, lighting, fire suppression, or radiation protection). It also does not address other Habitat Systems such as Electrical Power production or in-situ resource utilization (ISRU) functions associated with collecting and transporting water-laden Martian regolith to the Habitat.

Each ECLSS module (hereafter just called ECLSS) consists of a single landed capsule that interfaces with the other surface structures and systems (e.g. power production, command and control, and regolith supply). As requested by Mars One, the ECLSS provides part of the required ISRU functionality – *in-situ* resource processing (ISRP) is performed to extract water (H_2O) from externally supplied Martian regolith and nitrogen (N_2) and argon (Ar) from the Martian atmosphere. Prior to first crew arrival, the ECLSS generates the habitat's pressurized breathable atmosphere (10.2 psia, 2.5 psi O_2, balance N_2 and Ar), as well as stored O_2, and H_2O. The ECLSS also maintains CO_2 and trace contaminants in the habitat atmosphere below harmful levels. After crew arrival, the ECLSS continues to deliver N_2, Ar, O_2, and H_2O, and remove CO_2 and trace contaminants to meet crew metabolic needs, maintain a safe breathable atmosphere, and provide makeup quantities for nominal leakage and contingency operations.

The conceptual design assessment will also document the approach to providing other ECLSS functions that were not specifically requested by Mars One but are considered primary ECLSS functions. These additional functions include positive pressure relief, internal habitat air filtration, air temperature control and circulation, fire detection and notification, air quality monitor, potable water quality monitor, and thermal control (heat collection, heat transport, heat rejection, and insulation).

Figure 1 illustrates the arrangement of two ECLSS, two rover, and two supply landers after arrival of the first crew. The figure provides a cut-away view of one of the two inflatable habitat module concepts.

Figure 1: External view of the Mars One Habitat Concept after the first crew landing (inflatable habitat modules are out of view behind the landers).

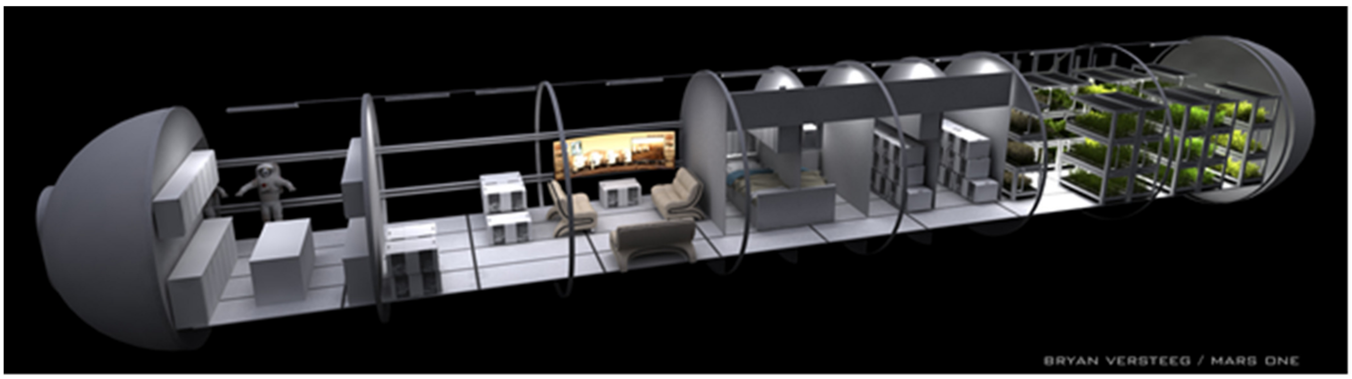

Figure 2: Internal view of the Mars One Habitat Housing Concept

1.3 Purpose

The purpose of this Design and Development book is to document the evolution of the Habitat ECLSS architecture prior to formal definition of the Development Component Baseline. As such, this document will serve as the Design Requirements Baseline, Functional Baseline, and Level II Allocated Baseline as defined by Section 5.0 of Paragon's Configuration Management Plan (E999019).

1.4 Methods

Design, development, documentation, and data management will be in accordance with Paragon's established processes.

1.5 Mission Concept of Operations

1.5.1 Phase 1: 1st Rover Delivery

In 2022 the first settlement rover will land on Mars. While the general location of the outpost will be known, the rover's task is to find the ideal spot within the area. As with the Curiosity Mars Rover, the 6-40 minute round-trip delay in communication (depending upon the positions of the Earth and Mars in their orbits) requires that the rover has some autonomy while much of its functions will be controlled by instruction from Earth. A video stream will be broadcast on Earth 24/7/365.

(courtesy mars-one.org)

Habitat ECLSS participation will be primarily to understand the environmental details of the chosen location and validate the ECLSS design which is well into qualification testing.

1.5.2 Phase 2: Cargo Missions

In 2025 all initial cargo components of the settlement have reached their destination in six separate landers. Two living units, two life support units, a supply unit, and another rover arrive on Mars. The two rovers take all components to the settlement location, deploy external structures such as solar panels and radiators, and prepare for the later arrival of Mars Team One, the first humans on Mars. A second video stream will be broadcast to Earth 24/7/365.

(courtesy mars-one.org)

The Habitat ECLSS will be required to be fully functional on two of the vehicles. Operations will be conducted autonomously with robotic assistance. ECLSS operations will commence with water extraction from externally supplied Martian regolith and nitrogen and argon extraction from the Martian atmosphere. The ECLSS initiates pressurization of the habitat with a breathable atmosphere (10.2 psia, 3.1 psi O_2, balance N_2 and Ar), and storage of oxygen and potable water.

1.5.3 Phase 3: System Checkout and Crew Launch Verification

All water, oxygen and atmosphere production will be ready by early 2026, which is when the Earth crew is granted the go-for-launch of Mars Team One. Each component of the Mars transit vehicle is launched into a low Earth orbit and linked. In September history is made as the first four astronauts are launched on their journey to the Red Planet. Every part of this adventure will be broadcast to Earth 24/7/365.

(courtesy mars-one.org)

Prior to the crew's departure, the two Habitat ECLSS modules will have achieved full operational capability for water and atmosphere production. Unequivocal evidence of success will be two fully pressurized surface habitat modules along with stored oxygen and water at target levels. Along with other critical factors, the decision to launch the crew will rely upon the success of the Habitat ECLSS to generate the required breathable atmosphere.

1.5.4 Phase 4: First Crew Arrival

The Mars Team One astronauts land in 2027 – the first humans to set foot on Mars! Once settled in, their first tasks include installing the connecting passageways between the individual capsules, configuring and activating the food production units, and assembling the remaining solar photovoltaic panels. Their epic exploration of Mars, their new home planet begins, with everyone on Earth engaged in the 24/7/365 broadcast. A few weeks later, five cargo missions arrive, bringing additional living units, life support units, and a third rover.

(courtesy mars-one.org)

The Habitat ECLSS at this point in time will have been operational for two years. Soon after arrival, regular maintenance by the crew will be performed to ensure continued operation. Water production by two fully functional and independent ECLSS modules will provide for a comfortable (water-rich) quality of life. In the event of contingency operations, each ECLSS will sustain the entire habitat in a water conservation mode until repairs are made or repair parts are supplied from Earth. In addition, a 30-day storage buffer of water, oxygen, and N_2/Ar is maintained to accommodate the temporary shut-down of both ECLSS units.

A short time after the arrival of the first crew, the infrastructure for the second crew arrives and is installed by the first crew. Four ECLSS modules are now available to nominally sustain the first crew and to complete pressurization of the two new living modules. The two new ECLSS modules provide additional redundancy for the first crew in the event of contingency operations.

1.5.5 Phase 5: Crew Expansion

In 2029 Mars Team Two, the second crew of four astronauts, lands. They are received by their predecessors who have completed the construction of the settlement. As successive Mars One Teams arrive, the settlement will grow in its capacity for scientific research, experiments, and exploration of Mars, with high definition video streams providing viewers on Earth with ample engagement.

(courtesy mars-one.org)

Shortly after arrival of the second crew, six Habitat ECLSS modules will be in place and operating under nominal conditions. The Phase 4 contingency mode assumptions of a 30 day system shut-down is now replaced with an operational mode of water conservation and use of the remaining systems with the assumption that there will be six ECLSS modules at the Mars One base.

Each time a crew of 4 lands, two additional ECLSS modules will accompany them until that strategy evolves to a better solution (e.g. commencement of in-situ manufacturing of spares).

1.6 Reference Documents

Table 1: Paragon Documents

Doc Number	Title
E999019 C	Configuration Management Plan
807300008NC	Mars One Surface Suit System Conceptual Design Book
899900734A	Technical Assistance Agreement Between Paragon Space Development Corporation and Stiching Mars One

Table 2: Other Documents

Doc Number	Title
SP-3006	Bioastronautics Data Book
JSC-20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants(SMAC)
JSC-63414	Spacecraft Water Exposure Guidelines(SWEGs)
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
MIL-STD-461-F	Requirements for Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
JPR 8080.5	JSC Design and Procedural Standards
JSC 65828	Structural Design Requirements and Factors of Safety for Space Flight Hardware
JSC 65829	Loads and Structural Dynamics Requirements for Space Flight Hardware
JSC 28918	EVA Design Requirements and Considerations
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-6016	Standard Material and Process Requirements for Spacecraft
NASA-STD-5017	Design and Development Requirements for Mechanisms
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
NPR 7150.2A	NASA Software Engineering Requirements
NASA-STD-8719.13B	Software Safety Standard

Doc Number	Title
NASA-GB-8719.13	Software Safety Guidebook
NASA-STD-5005C	Standard for the Design and Fabrication of Ground Support Equipment
ANSI/AIAA S-081A	Space Systems - Composite Overwrapped Pressure Vessels (COPVs) July 24, 2006
S-080-1998e	AIAA Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
AIAA S-120-2006	Mass Properties Control for Space Systems

2 System-Level Design Drivers

2.1 Overview

The following system-level Design Drivers are used in the derivation of the ECLSS requirements and are derived from preliminary information exchanges with Mars One, presentations, physical conditions of the Mars environment, and initial assessments made by Paragon. Some modification of the Mission CONOPs (Section 1.5) and these System-Level Design Drivers are expected during the early conceptual development phase and they will impact the subsequent ECLSS requirements. As such, these initial inputs to the development of the ECLSS architecture should be reviewed, vetted, and agreed too early to avoid significant impacts and costly corrections later in the program.

2.2 Atmospheric and Martian Surface Conditions Impact Upon Habitat ECLSS

[SLDD.xxx] Atmospheric Composition

Consists primarily of carbon dioxide (~95%), nitrogen (~2.7%), argon (~1.8%), and carbon monoxide (~0.08%).

Impact to the Design: Atmospheric nitrogen and argon are in sufficient quantity to be captured and purified and used as balance gas in the pressurized habitat. Toxic carbon monoxide is also at significant enough concentration that it must be purposely excluded during the production of nitrogen and argon or actively removed by the Habitat ECLSS trace contaminant control assembly.

As a natural resource, the ability to utilize CO_2 as a source of O_2 may be considered. The toxicity effect of CO_2within the habitable volume requires protection from CO_2. As the crew enters and exits the habitat, there is potential for CO_2 contamination of the pressurized airlock volume. Also, if not controlled, condensation of expired H_2O in the airlock by crew in a high CO_2 environment may result in the formation of carbonic acid which can increase corrosion rates on condensing surface. Thus the system-level design must be able to accommodate exposure to carbonic acid, preclude its formation, or employ a combination of both approaches.

[SLDD.xxx] Atmospheric Pressure

The average atmospheric pressure is 600 Pa (~0.087 psi).

Impact to the Design: The low pressure will necessitate the need for maintaining higher pressures within the habitable volumes. With a lower pressure outside of the cabin, contamination of internal atmosphere is significantly reduced; however, it requires management of crew ingress/egress between the habitat and the external environment to minimize habitat atmospheric losses during airlock depress and repress.

Mars-One currently plans to place the Mars One habitat at an altitude of -4km which will increase the ambient atmospheric pressure to ~1000 Pa (~0.145 psi). Although the pressure difference is negligible, consideration of the difference in external pressure should be considered in the system performance margins. Given that the targeted landing sites are at lower elevations (approximately -4 km), the pressure may be marginally higher.

Additionally, although not part of the Habitat ECLSS, protection against atmospheric leakage and timely detection and repair of leaks will be critical to the long-term success of the Surface Habitat. The nominal and contingency leakage rates will drive sizing of gas production subsystems as well as storage buffers.

Careful arrangement and inclusion of the ability to connect or isolate discrete pressurized volumes within the Surface Habitat should be considered and implemented to minimize the magnitude of worst-case contingency leakage rates and volumes.

Additionally as the surface Habitat matures, maximally increasing habitable pressurized volume will increase safety by increasing the time available to respond to, and recover from contingency leak events.

[SLDD.xxx] Temperature and Thermal Environment

Annual average temperature range is -140°C (-220°F) to 20°C (70°F).

Impact to the Design: Solar cycle is very similar to Earth, but the variation is more extreme. Selection of landing site will have an impact on the temperature swings experienced by the habitat.

Coupled with other factors such as atmospheric pressure, frequency of dust storms, and reliable access to existing thermal sinks (e.g. atmosphere, sky or subsurface), trade a trade study must be completed to determine the most practical method(s) to reject heat from the surface habitat to the external environment.

[SLDD.xxx] Wind-blown Regolith (i.e. dust)

Martian weather includes dust storms with potentially high wind velocity and lingering dust clouds.

Impact to the Design: Dust storms are known to occur. Wind loads are expected to be minimal (dynamic pressure is dependent on density) though not fully insignificant on large surfaces. Contamination of external vents, ports, door locks, seals, solar arrays, etc. will need to be mitigated. True understanding of weather and dust composition is not well understood and these conditions are untested. Materials of construction and designs must be evaluated for abrasion, wear, and durability against wind-blown regolith. This is of particular concern for solar voltaic power production as the electrical power that runs the ECLSS must be supplied continuously (excluding nominal diurnal variation).

[SLDD.xxx] Electrostatic Regolith

Martian regolith is electrostatically charged.

Impact to the Design: The regolith will likely be attracted to space suit materials of construction as well as other hardware that is moved in and out of the habitat. As a result, it will be brought into the habitable volume, even with active mitigation strategies.

[SLDD.xxx] Superoxides in Regolith

Martian regolith contains "superoxides".

Impact to the Design: In the presence of ultraviolet radiation, superoxides break down organic molecules. It is unknown what exact effects the superoxides are going to have within the habitable volume but the expectation is that materials such as polymers and elastomers may degrade relatively quickly and introduce trace contaminants into the Habitat atmosphere if not carefully screened for compatibility. Hence the need to ensure the surface habitat external airlock incorporates features that reduce the unplanned introduction of Mars regolith to lowest practical levels.

Methods must be developed to safely handle, collect, remove, and/or neutralize regolith that migrates into the habitat pressurized volume.

[SLDD.xxx] Radiation

There is very limited protection from the atmosphere or any from the planetary magnetic field.

Impact to the Design: Although not considered as part of the ECLSS, maintaining a habitat includes mitigating adverse health effects from exposure to solar particle event (SPE) radiation and Galactic Cosmic Radiation (GCR). Shielding will be required, whether natural regolith or other material (water being an effective material).

[SLDD.xxx] Gravity

Mars has approximately 3/8th gravity of Earth.

Impact to the Design: Given the appreciable gravitational field on Mars, technologies that exploit passive gravitational force should be utilized whenever practical to simplify operations. Analysis and some design modifications to existing mature terrestrial processes will be required to accommodate changes in particle and fluid behavior in the reduced gravity environment (e.g. changes in the behavior of sloshing fluids in a tank or gravitational separation of particles or liquids from an airstream). The reduction of buoyancy driven convection relative to Earth-nominal will also have to be considered with regards to heat transport and atmospheric mixing.

[SLDD.xxx] CONOPS and Terrain

Habitat site and terrain need to be understood.

Impact to the Design: Location of habitat on Martian surface will have an impact on environmental conditions, water access, etc. Surface roughness will determine accuracy and safety of habitat placements. Leveling will most likely be required (of either site or habitat) to achieve sufficient control of gravity dependent processes.

2.3 Habitat ECLSS Design

[SLDD.xxx] Designed for Mars Surface Operations

A separate ECLSS will be used for the trans-Mars phases of the mission. The ECLSS specified here will be designed specifically for usage after landing on Mars.

Impact to the Design: We do not have to directly consider the environments and conditions of other mission phases and may be considered payload in transit to Mars. It is noted that there may be some components (e.g. pumps, valves, accumulators, controllers, fittings, etc.,) that could be utilized in both systems. However, no dual use is contemplated at this time.

[SLDD.xxx] Mass and Volume

It is anticipated that the mass and volume of the Habitat ECLSS, support equipment, and spare parts is a significant factor for both launch cost and volume capacity.

Impact to the Design: There has always been an emphasis for compact, lighter, more robust space hardware across every space program. Although mass and volume may not be an issue on the Martian surface, the transportation costs associated with delivering the ECLSS to the surface will drive the ECLSS development costs (the lower the allowable mass and volume, the higher the development costs). ECLSS mass and volume targets will be relaxed with emphasis on robustness and simplicity. This increases reliability and the mission critical life support functions while minimizing development costs. It is critical that launch mass and volume limitations be defined early in the program as imposed limitations will lead to increased costs in the development of the ECLSS as more complex, efficient, and lower mass/volume product solutions are developed to meet launch constraints.

[SLDD.xxx] Operations

The ECLSS should be simple to operate.

Impact to the Design: ECLSS controls should involve simple automation where reasonable to reduce the workload on the crew. Once switched on, most operations such as pressure and temperature control should be automatic with crew alarms and some automatic responses to wear, breakdowns, and emergency conditions.

[SLDD.xxx] Instrumentation

Sufficient instrumentation will be needed for the crew to fully understand how the ECLSS is operating and to properly diagnose and fix wear, breakdowns, and emergencies.

Impact to the Design: Reasonably complete and redundant controls and instrumentation will be needed for the crew. Continuous monitoring by an Earth-based mission control is not realistic during crewed operations though a basic telemetry stream should be available and some remote command capability in case of emergencies might be considered.

[SLDD.xxx] Maintenance

The ELCSS must be maintainable by a limited crew with limited supply of tools and equipment and extremely costly and infrequent resupply.

Impact to the Design: Design for simplicity, reliability, and ruggedness. First objective should be to reduce the need for maintenance; second should be to make maintenance easy; and third should be to minimize limited life items that require replacement. It may be possible to eventually manufacture some replacement components on Mars.

[SLDD.xxx] Repair, Salvage, & Reuse

New equipment is planned to be introduced by supply flights from Earth every two years. Redundancy and reparability will be needed in the meantime.

Impact to the Design: Even with resupply, parts actually on Mars will be valuable for repair, salvage, and reuse. It is anticipated that all systems will be designed for easier repair, salvage, and reuse than has been traditional for spacecraft. Additionally, Mars One will implement sparing and line replaceable units at a much lower level than employed by previous spacecraft such as the International Space Station (ISS). This change does not require the development of new technology – it just requires an adjustment to the sparing philosophy and quite a bit more engineering design rigor to define and implement common interfaces, mechanical attachments, and interfaces at the lowest practical level.

[SLDD.xxx] No New Materials, Physical Processes, or Technologies

The Mars One Habitat ECLSS must utilize existing materials, physical processes and fundamental technologies to minimize technical and cost risks associated with developing the Habitat ECLSS.

Impact to the Design: The Habitat ECLSS design must make maximum use of existing materials, physical processes and technologies. It is understood that this will necessitate the design, manufacture, and qualification of new hardware products that build upon proven and existing life support technologies (whether they have traceability to aerospace or terrestrial origins). Transporting sufficient hardware and system mass to the surface of Mars is the primary issue, and Mars One has begun to address this by laying out their launch mass and frequency approach. A fundamental variable that must be carefully assessed at the program level is the actual mass required to reach the surface to ensure the ability of the crew to survive and prosper.

2.4 Other Considerations For Habitat ECLSS

[SLDD.xxx] Plant Growth Support

It is understood that from the very first mission, the crew will incorporate plant growth to improve quality of life. However the Habitat ECLSS utilizes a strictly physiochemical architecture to provide all required functionality. It is understood that as the outpost evolves, bioregenerative life support (i.e. food production, atmosphere revitalization, and primary water purification from plants) will be incorporated into the functional life support system architecture. In addition to growing the plants and revitalizing the atmosphere, other bioregenerative life support or Controlled Ecological Life Support System (CELSS) functions that have been developed by NASA and other space agencies will be implemented. These include development of palatable and nutritional plant-based diets, processing raw agricultural products into foodstuffs, implementation of efficient lighting, establishment of optimized and separate zones for crew habitation and plant growth, and recovering/recycling nutrients from the inedible plant biomass. An evolutionally approach to integrating closed-loop bioregenerative life support will be undertaken as the habitat grows and eventually, bioregenerative life support processes will dominate and be augmented by limited physiochemical processes.

Impact to the Design: Initially, the integration of low levels of plant growth will have minimal impact to the design and operation of the physiochemical-based ECLSS. However, as Mars One intends to introduce aspects of bioregenerative life support as soon as possible, more work beyond the scope of this initial effort will be required to ensure the continuous and uninterrupted operation of the physiochemical ECLSS no matter what the state of bioregenerative life support.

[SLDD.xxx] Planetary Protection Requirements

Many nations have agreed to minimize the transfer of terrestrial biological material to other planets and most Mars programs have implemented methods to minimize the transfer of biological materials by attempting to remove them from spacecraft during the ground processing phase before launch.

Impact to the Design: With a permanent Mars outpost, the introduction of terrestrial biological material to the external environment is certain to occur. It need to be determined early in the mission development phase to what extent, if any, methods are going to be implemented to minimize material transfer. Early on in the development of the surface habitat complex, the environment external to the habitat is likely to be a practical location to inert and store biological waste materials (in sealed containers if required to comply with planetary protection protocols). Later as the habitat infrastructure grows and bioregenerative life support is implemented, these stored biological materials can be processed to recover useful (e.g. inorganic and organic nutrients that can be repurposed for plant growth).

[SLDD.xxx] In-Situ Resource Utilization (ISRU)

From the outset, the life support approach for Mars One is to live off the land to the maximum extent possible. And the principle resource (and the single greatest one by mass needed to sustain life) is water. It has been proven that Mars has significant water resources located just a few centimeters below the regolith in many locations across the planet. Like all explorers that have established new outposts previously in human history, Mars One must make maximum use of the local resources to sustain the crew. Thus in situ resource utilization (ISRU) *and specifically water extraction from subsurface ice must be a fundamental requirement of the Mars One mission plan from the outset. Extracted water will be used for consumption, cleaning, oxygen production, and eventually plant growth.*

Nitrogen and argon comprise approximately 3.8% of the Martian atmosphere. These gases must be extracted from to maintain the composition and pressure of the habitat atmosphere as replenishment due to nominal leakage and airlock cycling as well as recovery from contingency leak events must be accommodated.

Impact to the Design: Although a variety of physical processes for extracting water from Mars regolith and nitrogen and argon from the atmosphere are well known, a spaceflight qualified ISRU collection/extraction system must be designed and qualified. A system-level design trade should be conducted to determine the optimum location and configuration of all ISRU subsystems (i.e. collection, transport, extraction, and waste disposal).

It is also noted that during the collection of nitrogen and argon, significant quantities of concentrated carbon dioxide will be generated if cryogenic separation is utilized. This additional resource should be stored and repurposed for uses ranging from a sweep gas to remove dust from space suits prior to entering the airlock to the primary spacesuit coolant. It is also possible, naturally warmed and compressed CO_2 gas could be expanded through a turbine to generate electrical power.

[SLDD.xxx] In-Situ Manufacturing

Spares and consumables will dominate Earth resupply cargo up until the point that in situ manufacturing is made possible by building up a Mars manufacturing capability. As the Mars One goal is to steadily build from a permanently staffed outpost to a permanent and largely self-sufficient settlement, it is understood that reliance on resupply must be drastically reduced as time progresses and the habitat increases in size and population. It will take significant time to build the infrastructure required to develop a manufacturing base, but this capability must be developed if a permanent settlement is to be achieved. As recorded in the course of human history, self-sufficiency is a given characteristic of permanent and successful human settlements.

Like most human settlements, imported goods would eventually be reduced to those that cannot be obtained locally. When it comes to sustaining life, Mars is relatively abundant in the essentials (oxygen, carbon, hydrogen, and nitrogen which comprise ~ 96% of your average human), so once the settlement is mature, remote supply of life support essentials will be limited to trace elements and organic compounds that are chemically bound in waste products and that cannot be effectively recycled. With regards to manufacturing mechanical components, it is understood that Mars One will incorporate the latest advances in manufacturing technology (e.g. additive manufacturing).

Impact to the Design: Although it is expected to offer future benefits to the Mars One habitat, operation of the physiochemical Habitat ECLSS will not rely on in-situ manufacturing to meet performance and reliability, and maintenance requirements.

[SLDD.xxx] Electrical Energy Availability

Access to reliable electrical energy is as important as any of the other ISRU derived resources (i.e. N_2/Ar pressurant gas and water from regolith). In fact, without the electrical energy first being available, there can be no harvesting of these essential life support commodities. In the original program overview documentation supplied to Paragon by Mars One, there is a 4X seasonal variation in available electrical energy production. At the high end (~1070 kW-hr/day assuming 15.5 hours of light) and average (670 kW-hr/day), there should not be any issues with available electrical energy. However at the low end (~267 kW-hr per day assuming 8.5 *hours of light), energy required to operate the ECLSS and other habitat systems may exceed the entire available electrical energy production. In addition to seasonal variations, diurnal variations must also be taken into account with a majority of the primary and power intensive ECLSS functions being performed during the day when power is maximally available*

Impact to the Design: The ECLSS must be designed to accommodate seasonal and diurnal swings in available electrical energy. Given this reality, the system and subsystem peak production rates are likely to increase to compensate for low-energy, low-production periods. This also implies that storage tanks and buffers will need to be larger to allow stockpiling of resources during high power energy periods and increased use of stored resources during low energy periods if minimum electrical energy levels are not increased.

The next design iteration should include increased fidelity of electrical energy availability to better model ECLSS production rates and buffer sizing requirements. It is recommended that additional trades be conducted at the Mars One system level to determine if it is more advantageous to increase minimum electrical energy production as opposed to increasing ECLSS peak processing rates and buffer sizes.

Also, significant effort during detailed design should also be given to maximally reducing leakage and reducing atmospheric gas lost during airlock cycling to minimize ISRU electrical energy requirements.

3 Level I Habitat ECLSS Requirements

Figure 3 outlines the baseline architecture to illustrate the major functions of the Habitat ECLSS. As previously noted, the ECLSS conceptual design includes contemplation of ECLSS functions not specifically identified in the Mars One request for proposal (RFP), but they are contemplated and included in the proposed conceptual design presented here.

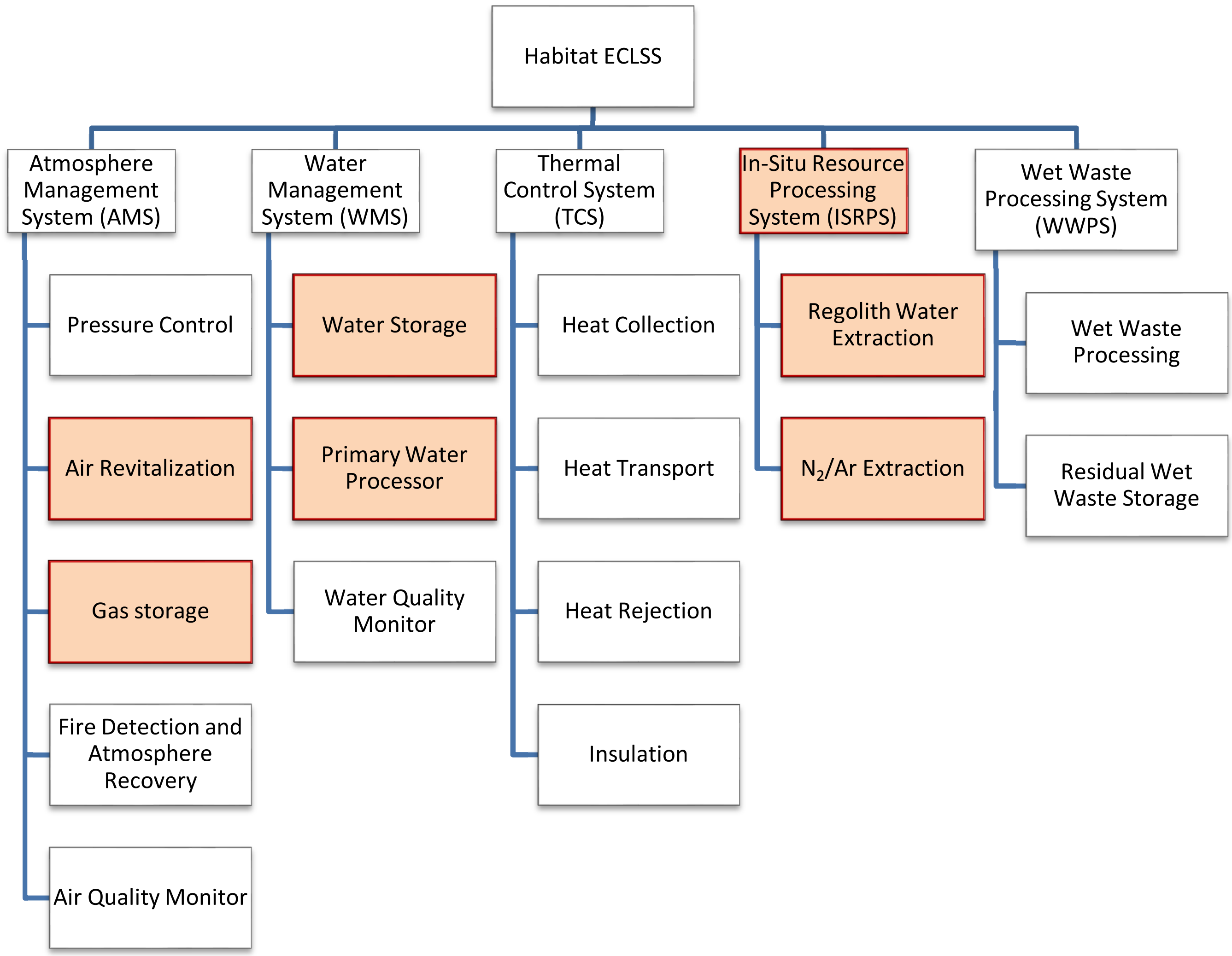

Figure 3: The Mars One Habitat ECLSS Functional Breakdown with ECLSS functions specified in the RFP highlighted. All other functions are contemplated and included in the evolving conceptual design.

3.1 Functional Requirements

3.1.1 General

[ECLSS.xxx-PGM] Crew Size: The ECLSS shall meet all functional and performance requirements for a nominal crew size of two (2) and a contingency crew size of four (4).

Rationale: This is a Mars One program requirement. During nominal operations, two ECLSS modules are used to sustain a crew of four (4). During contingency operations, one (1) ECLSS module must be able to sustain a crew of four (4) until contingency operations are concluded.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Pressurized Volume: The ECLSS shall meet all functional and performance requirements given a habitat free volume of 500 m^3 for a nominal crew size of two (2) and a contingency crew size of four (4).

Rationale: This is a Mars One program requirement. During nominal operations, two (2) crew members reside in each of the two (2) Habitat modules. During contingency operations, four (4) crew members reside in one (1) Habitat module. The condition remains until contingency operations are concluded.

Verification: (IDAT) – TBD

3.1.2 Atmosphere Management System (AMS)

[ECLSS.xxx-PGM] Habitat Atmosphere Pressure: The AMS shall maintain the habitat atmospheric pressure within allowable limits.

Rationale: Maintaining proper pressure is required for crew comfort and survivability as well as habitat structural limits.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Breathable Atmosphere: The AMS shall revitalize and maintain a safe, breathable, and comfortable atmosphere for the crew and equipment within the habitat.

Rationale: Maintaining proper O_2, CO_2, trace contaminant, particulate, temperature, humidity, and circulation levels throughout the habitat ensures crew comfort and survivability. Ventilation is needed for thermal control and for air revitalization. Proper atmosphere maintenance is also necessary for the proper functioning of equipment inside the Habitat. It is assumed that other non-ECLSS pressurized modules will contain additional boost fans, ducting, and vents to manage pressure drops and air circulation, and that these are not part of the ECLSS.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Gas Storage: The AMS shall provide for the storage of atmospheric gases to provide nominal buffering and contingency sources.

Rationale: Nominal diurnal, and possibly seasonal, variations will require atmospheric gas buffers to ensure continuous AMS functionality (e.g. more oxygen must be produced and stored during daylight hours when more electrical power is available). Some compressed oxygen will be delivered to the WMS for water processing needs and also to the Spacesuit System for Portable Life Support System recharging. In addition, contingency buffers of oxygen and nitrogen/argon are required to recover from leak events.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Fire Detection: The AMS shall monitor atmospheric constituents necessary to detect a fire.

Rationale: Detecting fires quickly is essential to crew safety and minimizing equipment damage. It is assumed that firefighting and control is included in Crew Systems and not part of the Habitat ECLSS. It is also assumed that habitat depressurization is not used to extinguish a fire.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Post-Fire Atmosphere Recovery: The AMS shall be capable of cleaning the habitat atmosphere following a fire event without the need to vent and then repressurize the atmosphere.

Rationale: Extinguishing a fire and reestablishing a safe breathable atmosphere without resorting to habitat depressurization is essential to crew safety and minimizing equipment damage.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Atmosphere Quality Monitoring and Reporting: The AMS shall be capable of monitoring and electronically reporting key atmosphere parameters (e.g. absolute pressure, O_2 partial pressure, humidity, temperature, and trace contaminant levels).

Rationale: Monitoring and reporting of AMS parameters is necessary to effect control for some functions (e.g. air temperature control) and to detect anomalous conditions (e.g. failing trace contaminant control).

Verification: (IDAT) – TBD

3.1.3 Water Management System (WMS)

[ECLSS.xxx PGM] Receive Non-Potable Water: The WMS shall receive non-potable water from the ISRUS and AMS.

Rationale: ISRU-derived water is the sole external source of water utilized by the Mars ECLSS. Habitat humidity condensate is a relatively clean water source that can be utilized in nominal or contingency operation modes to reduce the input of ISRUS-derived water.

[ECLSS.xxx PGM] Store Non-Potable Water: The WMS shall store non-potable water received from the ISRUS and AMS.

Rationale: Nominal diurnal, operations, and possibly seasonal, variations in non-potable water production rates will require non-potable water storage buffers to ensure continuous WMS functionality (e.g. more ISRU water is produced during daylight hours when more electrical power is available). In addition, a buffer capability is required to accommodate temporary increases of non-potable water that will occur when potable water production is stopped for nominal maintenance or contingency repair operations.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Generate Potable Water: The WMS shall generate potable water.

Rationale: Potable water will be used by the AMS to generate oxygen and by other non-ECLSS systems (e.g. crew metabolic and hygiene needs, food preparation, and Spacesuit Portable Life Support Subsystem recharge).

Verification: (IDAT) – TBD

[ECLSS.xxx PGM] Store Potable Water: The ECLSS shall store potable water generated by the received from the ISRUS and AMS.

Rationale: Nominal diurnal, operational, and possibly seasonal, variations in potable water production rates will require potable water storage buffers to ensure continuous WMS functionality (e.g. more potable water is produced during daylight hours when more electrical power is available). In addition, a buffer capability is required to accommodate temporary increased demand needs of stored potable water to accommodate nominal events (Spacesuit Portable Life Support Subsystem recharge) or to recover from contingency events.

Verification: (IDAT) – TBD

3.1.4 Thermal Control System (TCS)

[ECLSS.xxx-PGM] Heat Collection: The TCS shall collect heat from the crew and equipment to maintain temperatures for people, processes and equipment within allowable limits.

Rationale: Maintaining appropriate temperature ranges maximizes crew productivity and maintains the overall health of the crew. It is also necessary for the proper functioning of the equipment inside the Habitat.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Heat Transport: The TCS shall transport collected heat to the Heat Rejection Subsystem.

Rationale: It is expected that a combination of atmosphere circulation and pumped fluid loop convective heat transfer will be utilized to move heat collected from internal sources to the Heat Rejection Subsystem.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Heat Rejection: The TCS shall reject heat to the external environment.

Rationale: Heat rejection to the external environment is expected to be accomplished by a combination of conduction, radiation, and possibly convection. Detailed design is required to develop the closed solution.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Insulation: Reserved

Rationale: Insulation requirements and design solutions will be developed as part of the Mars One ECLSS Program, but it is assumed that the work will be managed and implemented at the appropriate system or subsystem level (e.g. habitat pressure vessel wall insulation requirements are levied on the Habitat Structures system)

Verification: (IDAT) – TBD

3.1.5 In-Situ Resource Processing System (ISRPS)

[ECLSS.xxx PGM] Receive Water-Laden Regolith and Return Water-Depleted Regolith: The ISRPS shall receive water-laden Martian Regolith from the external Regolith Supply and Return System (RSRS) and return water-depleted regolith to the RSRS for disposal.

Rationale: Externally supplied water-laden Martian regolith is the sole external source of water utilized by the Mars ECLSS. The RSRS is the external regolith mining and transport system that supplies water-laden regolith to the ISRPS and removes water-depleted regolith. While the fundamental physical processes are straightforward, careful design, development, implementation, and testing of the interface between the ISRUS and the RSRS will be required to ensure mission success as there is no opportunity for crew maintenance or repair during the first two years of operation.

[ECLSS.xxx-PGM] Extract and Supply Non-Potable Water: The ISRPS shall extract non-potable water from externally supplied Martian regolith and supply non-potable water to the WMS

Rationale: Living off the land is essential to a successful settlement. Externally supplied water is required to generate the potable water required to sustain the crew.

Verification: (IDAT) – TBD

[ECLSS.xxx PGM] Receive Mars Atmosphere: The ISRPS shall receive Martian Atmosphere.

Rationale: Externally supplied Martian atmosphere is the sole external source of Habitat Atmospheric pressurant gas (nitrogen and argon mixture) available to the Habitat ECLSS. While the fundamental physical processes are straightforward, careful design, development, implementation, and testing of the interface between the ISRUS and the Mars atmosphere will be required to ensure mission success as there is no opportunity for crew maintenance or repair during the first two years of operation.

[ECLSS.xxx-PGM] Extract and Supply Pressurant Gas: The ISRPS shall extract pressurant gas (nitrogen and argon mixture) from the Martian atmosphere and supply purified pressurant gas to the AMS

Rationale: Living off the land is essential to a successful settlement. Externally supplied pressurant gas is required to generate and maintain the atmosphere within the Surface Habit.

Verification: (IDAT) – TBD

3.1.6 Wet Waste Processing System (WWPS)

[ECLSS.xxx PGM] Receive and Store Wet Waste: The WWPS shall receive and store human metabolic, food, and hygiene wet waste from other Mars One Habitat Systems.

Rationale: Human metabolic, food, and hygiene wet waste represent significant quantities of water that must be continuously replaced by outside sources (i.e. ISRU derived water) if the water is not recovered. Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

[ECLSS.xxx PGM] Recover Non-Potable Water: The WWPS shall recover non-potable water and transfer it in vapor form to the habitat air circulation loop.

Rationale: The existing AMS air circulation and humidity condensation functions are readily adapted to collect, transport, and condense, non-potable water recover from wet waste.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Store Residual Wet Waste Solids: The WWPS shall store residual wet waste solids for future use.

Rationale: Living off the land is essential to a successful settlement. Future recovery of organic and inorganic elements and compounds will be essential as the habitat grows in size and increases mass-loop closure.

Verification: (IDAT) – TBD

3.2 Performance Requirements

3.2.1 General

[ECLSS.xxx-SMA] Pre-Crew Arrival Performance: The ECLSS shall meet all pre-Crew Arrival performance requirements.

Rationale: This is a Mars One program requirement. The ECLSS must operate for two years prior to crew arrival to prepare the habitat for initial occupancy and generate contingency quantities of atmospheric gasses and potable water.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Nominal Performance: The ECLSS shall meet all nominal performance requirements for a crew size of two (2).

Rationale: This is a Mars One program requirement.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Contingency Performance: The ECLSS shall meet all contingency performance requirements for a crew size of four (4).

Rationale: To accommodate an entire system shut down of a habitat, crews may transfer from one habitat segment to another segment. This contingency mode assumes at least one of the two ECLSS modules is fully functional.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Short-Term Contingency Duration: A short term contingency duration shall be assumed to last thirty (30) days (TBR).

Rationale: To accommodate nearly complete shutdown of both ECLSS units, whether it be for repair, lack of sufficient electrical power (e.g. extended dust storm reduces solar power production), or any other reason.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Long-Term Contingency Duration: A long term contingency duration shall be assumed to last two (2) years (TBR).

Rationale: To accommodate nearly complete shutdown of one ECLSS unit, whether it be for repair, reduced electrical power (e.g. permanent reduction in available solar power production), or any other reason. Two years is the nominal Earth resupply interval. This requirement remains despite the fact that a 3rd ECLSS unit is scheduled to arrive immediately after the first crew. It remains as it cannot be assured that the 3rd unit will be landed successfully.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Emergency Life Support: The ECLSS shall provide at least 30 days (TBR) of life support consumables after the failure of external radiators and solar arrays.

Rationale: In the case of the failure of external resources, the Habitat ECLSS must be able to provide life support for a sufficient time for the crew to repair the external systems. Emergency life support includes oxygen for metabolic consumption and leakage make-up, pressure control to prevent pressure dropping below 52 kPa (TBR), some thermal control, and contaminant control. The assumption is that a long duration dust storm could deposit a significant amount of dust on the radiators and solar arrays resulting in failure of functionality until the systems can be restored.

Verification: (IDAT) – TBD

3.2.2 Pre-Crew Arrival Performance

3.2.2.1 Atmosphere Management System

[ECLSS.xxx-PGM] Pre-Crew O_2 Production Rate: The AMS shall produce O_2 at a minimum average rate of 1.0 kg/day over 365 days of operation.

Rationale: This is sufficient O_2 to nominally pressurize the 500 m^3 habitat prior to crew arrival (118.4 kg) and store an additional 120 kg of pure O_2 and an additional 120 kg of O_2 mixed with N_2/Ar. Stored pure O_2 is sufficient to provide 30 days of oxygen for a crew of 4 with no *resupply. Stored O_2 mixed with N_2/Ar is sufficient to complete a single inflation of the 500 m^3 habitat (the O_2fraction of the atmosphere). It is noted that the habitat O_2 production rate specified here is higher than the Mars One initial target to ensure the habitat O_2 partial pressure is at least 17.2 kPa (2.5 psi) at the end of 365 days of operation. It is also higher to generate the additional O_2 that is to be combined and stored with the N_2/Ar.*

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew O_2 Partial Pressure Control: The AMS shall maintain the habitat oxygen partial pressure between 17.2 kPa (2.5 psi) (TBR) and 20.0 kPa (2.9 psi) (TBR) with the balance being a mixture of nitrogen, argon, carbon dioxide, water vapor, and other trace contaminants.

Rationale: The lower oxygen limit is above the hypoxia range and approximately equivalent to the oxygen partial pressure in Denver Colorado. The upper oxygen limit is equivalent to a maximum oxygen concentration less than 30% at a lower nominal cabin absolute pressure of 66.9 kPa (9.7 psia). It is expected that this upper limit allows a wide range of existing space certified materials of construction to be used with regards to flammability requirements. It is noted that even lower O_2 partial pressure levels may be possible, and more work will be required during detailed design to establish the final allowable O_2 partial pressure range.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew N_2/Ar Introduction Rate: The AMS shall introduce ISRU supplied N_2/Ar at a minimum average rate of 1.8 kg/day over 365 days of operation.

Rationale: This is sufficient N_2/Ar to pressurize the 500 m^3 habitat prior to crew arrival (320 kg) and store an additional 320 kg of N_2/Ar. Stored N_2/Ar (which is combined with O_2 at the nominal ratio prior to storage) is sufficient to complete a single inflation of the 500 m^3 habitat. It is noted that the N_2/Ar production rate specified here is 2X higher than the Mars One initial target to produce the stored N_2/Ar which Mars One originally did not request. It is also noted that a lower contingency N_2/Ar production rate and storage buffer size may be possible if contingency operation scenarios include operating the habitat safely at lower atmospheric pressure or completing repressurization of one 500 m^3 habitat using the stored gasses from both ECLSS units.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Habitat Absolute Pressure Control: The AMS shall maintain the habitat absolute pressure between 66.9 kPa (9.7 psia) and 70.33 kPa (10.2 psi) (TBR).

Rationale: A mixture of nitrogen, argon, oxygen, carbon dioxide, water vapor, and other trace contaminants comprise the habitat atmosphere. The lower absolute pressure limit is primarily to limit maximum possible oxygen concentration to less than 30% (when combined with the maximum allowable O_2 partial pressure), and secondarily to minimize hearing difficulties (hearing is reduced as atmospheric pressure decreases). The maximum absolute pressure limit is to minimize or eliminate the need to pre-breath pure oxygen before EVA's (will depend on final suit absolute pressure). It also reduces leak rates for nominal and contingency leaks, and limits pressure-induced structural loads on the habitat pressure vessel. It is noted that a lower absolute pressure range may be possible (perhaps 55-60 kPa), and more work will be required during detailed design to establish the final range.

[ECLSS.xxx-PGM] Pre-Crew Habitat Positive Pressure Relief: The AMS shall prevent the delta pressure between the interior of the habitat and the external Martian environment from exceeding 70.33 kPa (10.2 psid) (TBR).

Rationale: Positive pressure relief is necessary to prevent pressure-induced structural loads from exceeding design limits.

[ECLSS.xxx-PGM] Pre-Crew Atmospheric Particulate Matter Control: The AMS shall limit the concentration of particulate matter in the habitat atmosphere ranging from 5.0 x 10-4 mm (0.5 microns) to 0.1 mm (100 microns) in aerodynamic diameter to <0.2 mg/m^3

Rationale: Inhalation of particulates can cause irritation of the respiratory system and damage equipment if not controlled. Limits for particulates are based on OSHA standards. (Reference CxP 70024 Constellation Program Human-Systems Integration Requirements 3.2.1.6.3)

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Atmospheric CO_2 Control: The AMS shall maintain the average CO_2 partial pressure in the habitat below 507 Pa (0.0735 psi). (TBR)

Rationale: This is the current NASA 1000-day SMAC. A lower level may be medically required and latest NASA assessment should be considered.

[ECLSS.xxx-PGM] Pre-Crew Atmospheric Trace Contaminant Control: The AMS shall limit the concentrations of contaminants in the Habitat atmosphere below the 1000-Day Spacecraft Maximum Allowable Concentrations (SMAC) per document JSC-20584.

Rationale: Exposure to airborne trace contaminants can cause a wide range of adverse health effects to the crew.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Atmospheric Humidity Control: The AMS shall maintain the average atmospheric dew point in the habitat below 10 °C (50 °F).

Rationale: This is corresponds to approximately 43% relative humidity assuming an air temperature of 25.8 °C (75 °F) and is within the human comfort range. This level is also intended to be below the lowest surface temperatures in the habitat thus ensuring condensation does not occur.

[ECLSS.xxx- SMA] Pre-Crew Atmosphere Temperature Range: The AMS shall maintain the average atmospheric temperature in the habitat between 12 °C (53.6 °F) and 37 °C (97 °F) (TBR) prior to crew arrival.

Rationale: The low temperature limit is intended to limit the formation of water condensate around the Habitat while reducing the amount of emergency power needed for active heating. The high temperature limit is to reduce the amount of active cooling needed.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Pre-Crew Atmosphere Temperature Control: The AMS shall allow the average air temperature within the habitat to be controlled to within 1.5 °C (2.7 °F) (TBR).

Rationale: Individual comfort level and workload variations require some amount of air temperature control within the Habitat.

Verification: (IDAT) – TBD.

[ECLSS.xxx- SMA] Pre-Crew Sensible Heat Removal from the Atmosphere: The AMS shall remove at least 719 kW-hours (TBR) of sensible heat from the habitat atmosphere per day.

Rationale: From the original request for quote, available electrical energy on the longest day of the year is 909 kW-hr from the solar power arrays and 50 kW-hr, from the batteries. It is assumed that 75% of this energy is converted to heat within the pressurized habitat and that it is removed as heat from the atmosphere. Active and passive heat removal methods will be employed and developed during the detailed design to collect, transport, and reject this heat.

Verification: (IDAT) – TBD

[ECLSS.xxx- SMA] Pre-Crew Latent (Wet) Heat Removal from the Atmosphere: The AMS shall remove at least 4.4 kW-hours (TBR) of latent (wet) heat from the habitat atmosphere per day.

Rationale: This is approximately equivalent to four crew members expected metabolic water output (less water in urine and feces), or 6.6 kg-condensed water per day. It is expected that the complete Habitat ECLSS will be exercised prior to crew arrival to verify all systems are functioning. Therefor a pre-crew arrival test is assumed that would introduce a portion of the 4 crews equivalent metabolic water load into the atmosphere (i.e. simulated metabolic water from sweat and breathing). Other sources of water that can make their way to the atmosphere such as food preparation, hygiene, and water evaporated from waste have not been included at this time.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Pre-Crew Ventilation Rate: The AMS shall ventilate the Habitat at rates ranging from 4 to 20 air changes per hour (TBR).

Rationale: Ventilation is needed to minimize temperature gradients throughout the Habitat and to support air revitalization. The low rate is the minimum recommended for all spaces on Earth. The high rate is the minimum recommended for a high load environment (e.g. tavern or dusty facility). It is expected that this requirement will be allocated down to individual defined volumes within the habitat to optimize for air revitalization needs and power.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Fire Detection: The AMS shall autonomously detect a fire and notify the habitat master computer.

Rationale: Rapid detection of fire events within confined habitable spaces is critical to the immediate and long-term survival of the crew. Fires must be detected and suppressed before they can result in catastrophic structural failures of the pressure vessel or equipment. Similarly, airborne combustion products from the fire must be limited to prevent unrecoverable poisoning of the atmosphere.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Post-Fire Atmosphere Recovery: The AMS shall remove the following fire related contaminants at the rate shown in the table below at an initial inlet concentration as shown for a total mass as shown in the table below without needing to vent the atmosphere to the external environment and replenish it from stores. (TBR)

Contaminant	Initial Concentration (mg/m^3)	Average Removal Rate (mg/hr)	Total Removed Mass per Fire Event (mg)
Carbon monoxide	35.7	11900	17850
Acid Gas	18.4	6133	9200

Rationale: Adapted from CCT-ARS requirement by using the total removed mass and the requirement that all be removed in 1.5 hours. Initial concentration assumes the contaminant is uniformly distributed into the 500 m^3 habitable volume. CO and acid gases are the primary combustion event products that must be removed from the atmosphere. As this system is intended to be manually deployed following successful extinguishing of a fire by the crew, it is not certain that this will remain as a Pre-Crew requirement.

[ECLSS.xxx-PGM] Pre-Crew Atmosphere Quality Monitoring: The AMS shall continuously measure and report the following parameters to the habitat master computer: O_2, CO_2, absolute pressure, dew point, trace contaminants. (TBR)

Rationale: This is the minimum set of atmospheric parameters that must be measured to 1) verify the atmosphere is safe and breathable, and 2) provide input to the various control systems (e.g. oxygen partial pressure control and habitat absolute pressure control).More work is required to identify the minimum but sufficient set of trace contaminants that must be monitored and tracked.

Verification: (IDAT) – TBD.

3.2.2.2 Water Management System

[ECLSS.xxx-PGM] Pre-Crew Potable Water Production Rate: The WMS shall produce potable water at a minimum average rate of 5.9 kg/day over 365 days of operation.

Rationale: This is sufficient water to produce and store at least 1500 kg of potable water prior to the crew's arrival and supply sufficient water to the AMS to generate the required atmospheric and stored oxygen.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Potable Water Quality: The WMS shall produce potable water at the minimum water quality values shown in the table below.

Parameter	Value	Comment
Total Dissolved Solids (TDS)	< 500 mg/l	EPA Secondary Drinking Water Regulations
Total Organic Carbon (TOC)	< 20 mg/l	ISS Russian segment, potable water maximum allowable concentration (9SSMedical Operations Requirements Document, SSP 50260, Revision C, NASA Johnson Space Center, February 2006,Section 7.2 and Appendix D, Table D-1)
Total Coliform	< 5%	EPA MCL – No more than 5.0% samples total coliform-positive in a month. For water systems that collect fewer than 40routine samples per month, no more than one sample can be total coliform-positive per month. Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E. coli fecal coliforms, system has an acute MCL violation.
pH	5.5-9.0	Orion CEV-T-021 Potable Water Requirement
Quantity	0-1800 kg	Not a water quality requirement, but it is a requirement and included here for ease.

Rationale: Adapted from the Inspiration Mars program. The primary intent of this requirement is twofold – Establish purity levels that are sufficient to 1) provide water to the crew that is safe to drink with regards to inorganic, organic, and biogenic contaminants, and 2) preclude precipitation and fouling/clogging of wetted materials of construction. The later intent is to recognize the fact that inorganic and organic matter in the potable water stream may not be a health hazard, but they may cause problems with the hardware (e.g. clogging of a filter) or downstream systems that receive the potable water (e.g. the AMS water electrolyzer). A secondary intent of these requirements is to supply water that is aesthetically pleasing to the crew (i.e. the taste is acceptable).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Potable Water Quality Monitoring: The WMS shall regularly measure and report the following parameters to the habitat master computer: TDS, TOC, Total Coliform, and pH. (TBR)

Rationale: This is the minimum set of water quality parameters that must be measured to 1) verify the water is safe to drink safe and breathable, and 2) provide input to the various control systems (e.g. oxygen partial pressure control and habitat absolute pressure control). More work is required to identify the minimum but sufficient set of trace contaminants that must be monitored and tracked.

Verification: (IDAT) – TBD.

3.2.2.3 Thermal Control System

[ECLSS.xxx-PGM] Pre-Crew Sensible Heat Collection, Transport, and Rejection: The TCS shall collect, transport, and reject 719 kW-hours (TBR) of sensible heat

Rationale: From the original request for quote, available electrical energy on the longest day of the year is 909 kW-hr from the solar power arrays and 50 kW-hr, from the batteries. It is assumed that 75% of this energy is converted to heat within the pressurized habitat that must be removed by the TCS and rejected to the external environment.

Verification: (IDAT) – TBD.

[ECLSS.xxx- SMA] Pre-Crew Latent (Wet) Heat Collection, Transport, and Rejection: The AMS shall remove at least 4.4 kW-hours (TBR) of latent (wet) heat from the habitat atmosphere per day.

Rationale: This is approximately equivalent to four crew members expected metabolic water output (less water in urine and feces), or 6.6 kg-condensed water per day. It is expected that the complete Habitat ECLSS will be exercised prior to crew arrival to verify all systems are functioning. Therefor a pre-crew arrival test is assumed that would introduce a portion of the 4 crews equivalent metabolic water load into the atmosphere (i.e. simulated metabolic water from sweat and breathing). Other sources of water that can make their way to the atmosphere such as food preparation, hygiene, and water evaporated from waste have not been included at this time.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Pre-Crew Humidity Condensate Collection and Transport: The TCS shall be capable of collecting at least 6.6 kg of humidity condensate per day and transporting it to the WMS

Rationale: This is approximately equivalent to four crew members expected metabolic water output (less water in urine and feces), or 6.6 kg-condensed water per day. It is expected that the complete Habitat ECLSS will be exercised prior to crew arrival to verify all systems are functioning. Therefor a pre-crew arrival test is assumed that would introduce a portion of the 4 crews equivalent metabolic water load into the atmosphere (i.e. simulated metabolic water from sweat and breathing), where it will then be condensed on the habitat condensing heat exchanger and then transported to the WMS for re-processing to potable water

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Pre-Crew Peak Heat Rejection: The TCS shall be able to reject a peak heat load of 36 kW (TBR) for 2 hours (TBR).

Rationale: This is an estimated peak thermal load and duration assuming the peak load is 20% higher than the average of 724 kW-hr removed over 24 hours. The peak heat load can be managed by, any combination of active, passive, or storage methods.

Verification: (IDAT) – TBD.

3.2.2.4 In-Situ Resource Processing System

[ECLSS.xxx PGM] Pre-Crew Water-Laden Regolith Processing Rate: Over 365 days of operation, the he ISRUS shall process at least TBD kg/day of water-laden Martian Regolith to collect non-potable water.

Rationale: Externally supplied water-laden Martian regolith is the sole external source of water utilized by the Mars ECLSS. The quantity of regolith that must be processed to achieve the water production rate must still be determined.

[ECLSS.xxx-PGM] Pre-Crew Non-Potable Water Production Rate: Over 364 days of operation, the ISRUS shall extract at least 5.9 kg/day (TBR) of non-potable water from externally supplied Martian regolith and transfer it to the WMS.

Rationale: Living off the land is essential to a successful settlement. Externally supplied water is required to generate the potable water required to sustain the crew.

Verification: (IDAT) – TBD

[ECLSS.xxx PGM] Pre-Crew Mars Atmosphere Processing Rate: Over 365 days of operation, the ISRUS shall process at least TBD kg/day of Martian atmosphere to collect N_2 and Ar pressurant gas.

Rationale: Externally supplied Martian atmosphere is the sole external source of Habitat Atmospheric pressurant gas (nitrogen and argon mixture) available to the Habitat ECLSS.

[ECLSS.xxx-PGM] Pre-Crew Pressurant Gas Production Rate: Over 365 days of operation, the ISRUS shall extract at least 1.8 kg/day of pressurant gas (nitrogen and argon mixture) from the Martian atmosphere and transfer it to the AMS

Rationale: Living off the land is essential to a successful settlement. Externally supplied pressurant gas is required to generate and maintain the atmosphere within the Surface Habit.

Verification: (IDAT) – TBD

3.2.2.5 Wet Waste Processing System

Reserved

3.2.3 Post-Crew Arrival Nominal Performance

3.2.3.1 Atmosphere Management System

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal O_2 Production Rate: The AMS shall produce O_2 at a minimum average rate of 6 kg/day.

Rationale: This was a Mars One initial estimate and it bounds the metabolic requirement of the crew (3.56 kg O_2/day) and losses due to nominal leakage (0.57 kg/day) and airlock cycling (0.91kg/day). It is noted that EVA and airlock cycling frequency are still not finalized and that additional work is required to finalize these parameters and the planned losses due to airlock cycling. It is expected that airlock cycling will actually be lower than this initial estimate.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal O_2 Partial Pressure Control: The AMS shall maintain the habitat oxygen partial pressure between 17.2 kPa (2.5 psi) (TBR) and 20.0 kPa (2.9 psi) (TBR) with the balance being a mixture of nitrogen, argon, carbon dioxide, water vapor, and other trace contaminants.

Rationale: The lower oxygen limit is above the hypoxia range and approximately equivalent to the oxygen partial pressure in Denver Colorado. The upper oxygen limit is equivalent to a maximum oxygen concentration less than 30% at a lower nominal cabin absolute pressure of

66.9 kPa (9.7 psia). It is expected that this upper limit allows a wide range of existing space certified materials of construction to be used with regards to flammability requirements.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal N_2/Ar Introduction Rate: The AMS shall introduce ISRU supplied N_2/Ar at a minimum average rate of 7 kg/day (TBR).

Rationale: This was a Mars One initial target and it bounds expected losses due to nominal atmospheric leakage (1.53 kg/day) and airlock cycling (2.44 kg/day). It is currently assumed that there are 4 airlock cycles per day, the airlock is 10 m^3, and 1 m^3 of air is lost per cycle. It is noted that EVA and airlock cycling frequency are still not finalized and that additional work is required to finalize these parameters and the planned losses due to airlock cycling. It is expected that airlock cycling will actually be lower than this initial estimate.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Habitat Absolute Pressure Control: The AMS shall maintain the habitat absolute pressure between 66.9 kPa (9.7 psia) and 70.33 kPa (10.2 psi) (TBR).

Rationale: A mixture of nitrogen, argon, oxygen, carbon dioxide, water vapor, and other trace contaminants comprise the habitat atmosphere. The lower absolute pressure limit is primarily to limit maximum possible oxygen concentration to less than 30% (when combined with the maximum allowable O_2 partial pressure), and secondarily to minimize hearing difficulties (hearing is reduced as atmospheric pressure decreases). The maximum absolute pressure limit is to minimize or eliminate the need to pre-breath pure oxygen before EVA's (will depend on final suit absolute pressure). It also reduces leak rates for nominal and contingency leaks, and limits pressure-induced structural loads on the habitat pressure vessel.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Habitat Positive Pressure Relief: The AMS shall prevent the delta pressure between the interior of the habitat and the external Martian environment from exceeding 70.33 kPa (10.2 psid) (TBR).

Rationale: Positive pressure relief is necessary to prevent pressure-induced structural loads from exceeding design limits.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmospheric Particulate Matter Control: The AMS shall limit the concentration of particulate matter in the habitat atmosphere ranging from 5.0 x 10-4 mm (0.5 microns) to 0.1 mm (100 microns) in aerodynamic diameter to <0.2 mg/m^3

Rationale: Inhalation of particulates can cause irritation of the respiratory system and damage equipment if not controlled. Limits for particulates are based on OSHA standards. (Reference CxP 70024 Constellation Program Human-Systems Integration Requirements 3.2.1.6.3)

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmospheric CO_2 Control: The AMS shall maintain the average CO_2 partial pressure in the habitat below 507 Pa (0.0735 psi). (TBR)

Rationale: This is the current NASA 1000-day SMAC. A lower level may be medically required and latest NASA assessment should be considered.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmospheric Trace Contaminant Control: The AMS shall limit the concentrations of contaminants in the Habitat atmosphere below the 1000-Day Spacecraft Maximum Allowable Concentrations (SMAC) per document JSC-20584.

Rationale: Exposure to airborne trace contaminants can cause a wide range of adverse health effects to the crew.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmospheric Humidity Control: The AMS shall maintain the average atmospheric dew point in the habitat below 10 °C (50 °F).

Rationale: This is corresponds to approximately 43% relative humidity assuming an air temperature of 25.8 °C (75 °F) and is within the human comfort range. This level is also intended to be below the lowest surface temperatures in the habitat thus ensuring condensation does not occur.

[ECLSS.xxx- SMA] Post-Crew Arrival Nominal Atmosphere Temperature Range: The AMS shall maintain the average air temperature within the Habitat to the range of 18 °C (64 °F) to 27 °C (81 °F).

Rationale: Human comfort without protective clothing requires a fairly small range of air temperatures.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmosphere Temperature Control: The AMS shall allow the average air temperature within the habitat to be controlled to within 1.5 °C (2.7 °F) (TBR).

Rationale: Individual comfort level and workload variations require some amount of air temperature control within the Habitat.

Verification: (IDAT) – TBD.

[ECLSS.xxx- SMA] Post-Crew Arrival Nominal Sensible Heat Removal from the Atmosphere: The AMS shall remove at least 812 kW-hours (TBR) of sensible heat from the habitat atmosphere per day.

Rationale: From the original request for quote, available electrical energy on the longest day of the year is increased to 1070 kW-hr from the solar power arrays and 50 kW-hr, from the batteries. It is assumed that 75% of this energy is converted to heat within the pressurized habitat and that it is removed as heat from the atmosphere. The crew imparts an additional sensible heat load of 9.3 kW-hr. Active and passive heat removal methods will be employed and developed during the detailed design to collect, transport, and reject this heat.

Verification: (IDAT) – TBD

[ECLSS.xxx- SMA] Post-Crew Arrival Nominal Latent (Wet) Heat Removal from the Atmosphere: The AMS shall remove at least 35.1 kW-hours (TBR) of latent (wet) heat from the habitat atmosphere per day.

Rationale: This is approximately equivalent to condensing four crew members expected water output from the atmosphere (52.5 kg of water). This water load is considerably higher than the pre-crew arrival load as it includes recovered water from waste such as urine, feces, shower, oral hygiene, food preparation, and laundry.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Ventilation Rate: The AMS shall ventilate the Habitat at rates ranging from 4 to 20 air changes per hour (TBR).

Rationale: Ventilation is needed to minimize temperature gradients throughout the Habitat and to support air revitalization. The low rate is the minimum recommended for all spaces on Earth. The high rate is the minimum recommended for a high load environment (e.g. tavern or dusty facility). It is expected that this requirement will be allocated down to individual defined volumes within the habitat to optimize for air revitalization needs and power. This range is expected to be reduced as mixing, and convective heat transport needs are better defined.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Fire Detection: The AMS shall autonomously detect a fire and notify the habitat master computer.

Rationale: Rapid detection of fire events within confined habitable spaces is critical to the immediate and long-term survival of the crew. Fires must be detected and suppressed before they can result in catastrophic structural failures of the pressure vessel or equipment. Similarly, airborne combustion products from the fire must be limited to prevent unrecoverable poisoning of the atmosphere.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Post-Fire Atmosphere Recovery: The AMS shall remove the following fire related contaminants at the rate shown in the table below at an initial inlet concentration as shown for a total mass as shown in the table below without needing to vent the atmosphere to the external environment and replenish it from stores. (TBR)

Contaminant	Initial Concentration (mg/m^3)	Average Removal Rate (mg/hr)	Total Removed Mass per Fire Event (mg)
Carbon monoxide	35.7	11900	17850
Acid Gas	18.4	6133	9200

Rationale: Adapted from CCT-ARS requirement by using the total removed mass and the requirement that all be removed in 1.5 hours. Initial concentration assumes the contaminant is uniformly distributed into the 500 m^{3}habitable volume. CO and acid gases are the primary combustion event products that must be removed from the atmosphere. As this system is intended to be manually deployed following successful extinguishing of a fire by the crew, it is not certain that this will remain as a Pre-Crew requirement.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Atmosphere Quality Monitoring: The AMS shall continuously measure and report the following parameters to the habitat master computer: O_2, CO_2, absolute pressure, dew point, trace contaminants. (TBR)

Rationale: This is the minimum set of atmospheric parameters that must be measured to 1) verify the atmosphere is safe and breathable, and 2) provide input to the various control systems (e.g. oxygen partial pressure control and habitat absolute pressure control). More work is required to identify the minimum but sufficient set of trace contaminants that must be monitored and tracked.

Verification: (IDAT) – TBD.

3.2.3.2 Water Management System

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Potable Water Production Rate: The WMS shall produce potable water at a minimum average rate of 62 kg/day.

Rationale: This rate is significantly higher than the pre-crew production rate. The rate is achieved by a combination of recycling and ISRU resupply. Supplied water is used for the following functions: Shower, oral hygiene, urine flush, laundry, consumption/food preparation, metabolic oxygen production, makeup oxygen production for losses due to nominal atmosphere leakage and airlock cycling, and other miscellaneous losses. It is noted that this rate is lower than the original Mars One estimate of 100 kg/day.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Potable Water Quality: The WMS shall produce potable water at the minimum water quality values shown in the table below.

Parameter	Value	Comment

Total Dissolved Solids (TDS)	< 500 mg/l	EPA Secondary Drinking Water Regulations
Total Organic Carbon (TOC)	< 20 mg/l	ISS Russian segment, potable water maximum allowable concentration (9SS Medical Operations Requirements Document, SSP 50260, Revision C, NASA Johnson Space Center, February 2006, Section 7.2 and Appendix D, Table D-1)
Total Coliform	< 5%	EPA MCL – No more than 5.0% samples total coliform-positive in a month. For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month. Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E. coli fecal coliforms, system has an acute MCL violation.
pH	5.5-9.0	Orion CEV-T-021 Potable Water Requirement
Quantity	0-1800 kg	Not a water quality requirement, but it is a requirement and included here for ease.

Rationale: Adapted from the Inspiration Mars program. The primary intent of this requirement is twofold – Establish purity levels that are sufficient to 1) provide water to the crew that is safe to drink with regards to inorganic, organic, and biogenic contaminants, and 2) preclude precipitation and fouling/clogging of wetted materials of construction. The later intent is to recognize the fact that inorganic and organic matter in the potable water stream may not be a health hazard, but they may cause problems with the hardware (e.g. clogging of a filter) or downstream systems that receive the potable water (e.g. the AMS water electrolyzer). A secondary intent of these requirements is to supply water that is aesthetically pleasing to the crew (i.e. the taste is acceptable).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Potable Water Quality Monitoring: The WMS shall regularly measure and report the following parameters to the habitat master computer: TDS, TOC, Total Coliform, and pH. (TBR)

Rationale: This is the minimum set of water quality parameters that must be measured to 1) verify the water is safe to drink safe and breathable, and 2) provide input to the various control systems (e.g. oxygen partial pressure control and habitat absolute pressure control). More work is required to identify the minimum but sufficient set of trace contaminants that must be monitored and tracked.

Verification: (IDAT) – TBD.

3.2.3.3 Thermal Control System

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Sensible Heat Collection, Transport, and Rejection: The TCS shall collect, transport, and reject 900 kW-hour (TBR) of sensible heat daily.

Rationale: From the original request for quote, available electrical energy on the longest day of the year is 1020 kW-hr from the solar power arrays and 50 kW-hr, from the batteries. It is assumed that 75% of this energy is converted to heat within the pressurized habitat. In addition, the sensible heat output by the crew is 9.3 kW-hr. All sensible heat is removed by the TCS and rejected to the external environment. The sensible heat load can be managed by, any reasonable combination of active or passive methods.

Verification: (IDAT) – TBD.

[ECLSS.xxx- SMA] Post-Crew Arrival Nominal Latent (Wet) Heat Collection, Transport, and Rejection: The AMS shall remove at least 40 kW-hours (TBR) of latent (wet) heat from the habitat atmosphere per day.

Rationale: The latent load heat load that results from condensing water vapor generated by the 4 person crew, including all recovered water injected into the atmosphere as part of water recovery process is 35.1 kW-hr. The latent heat load can be managed by, any reasonable combination of active or passive methods.

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Humidity Condensate Collection and Transport: The TCS shall be capable of collecting at least 53 kg of humidity condensate per day and transporting it to the WMS

Rationale: This is greater than the expected water that will be condensed each day on the habitat condensing heat exchanger and then transported to the WMS for re-processing to potable water (52.5 kg).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Peak Heat Rejection: The TCS shall be able to reject a peak heat load of 42 kW (TBR) for 2 hours (TBR).

Rationale: This is an estimated peak thermal load and duration assuming the peak load is 20% higher than the average of 835 kW-hr removed over 24 hours. The peak heat load can be managed by any combination of active, passive, or temporary storage methods.

Verification: (IDAT) – TBD.

3.2.3.4 In-Situ Resource Processing System

[ECLSS.xxx PGM] Post-Crew Arrival Nominal Water-Laden Regolith Processing Rate: The ISRUS shall process at least TBD kg/day of water-laden Martian Regolith to collect non-potable water.

Rationale: Externally supplied water-laden Martian regolith is the sole external source of water utilized by the Mars ECLSS. The quantity of regolith that must be processed to achieve the water production rate must still be determined.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Non-Potable Water Production Rate: The ISRUS shall extract at least 9.0 kg/day (TBR) of non-potable water from externally supplied Martian regolith and transfer it to the WMS.

Rationale: Living off the land is essential to a successful settlement. Externally supplied water is required to generate the potable water required to sustain the crew. This production rate assumes the WMS achieves an 84% water recovery rate.

Verification: (IDAT) – TBD

[ECLSS.xxx PGM] Post-Crew Arrival Nominal Mars Atmosphere Processing Rate: Over 365 days of operation, the ISRUS shall process at least TBD kg/day of Martian atmosphere to collect N_2 and Ar pressurant gas.

Rationale: Externally supplied Martian atmosphere is the sole external source of Habitat Atmospheric pressurant gas (nitrogen and argon mixture) available to the Habitat ECLSS.

[ECLSS.xxx-PGM] Post-Crew Arrival Nominal Pressurant Gas Production Rate: The ISRUS shall extract at least 7 kg/day of pressurant gas (nitrogen and argon mixture) from the Martian atmosphere and transfer it to the AMS

Rationale: Living off the land is essential to a successful settlement. Externally supplied pressurant gas is required to generate and maintain the atmosphere within the Surface Habit. This was a Mars One initial target and it bounds expected losses due to nominal atmospheric leakage (<0.5%/day or 1.6 kg N_2/Ar per day) and airlock cycling.

Verification: (IDAT) – TBD

3.2.3.5 Wet Waste Processing System
Reserved

3.2.4 Post-Crew Arrival Short-Term Contingency Performance
Reserved

3.2.4.1 Atmosphere Management System
Reserved

3.2.4.2 Water Management System
Reserved

3.2.4.3 Thermal Control System
Reserved

3.2.4.4 In-Situ Resource Processing System
Reserved

3.2.4.5 Wet Waste Processing System
Reserved

3.2.5 Post-Crew Arrival Long-Term Contingency Performance

3.2.5.1 Atmosphere Management System
Reserved

3.2.5.2 Water Management System
Reserved

3.2.5.3 Thermal Control System
Reserved

3.2.5.4 .2.4.4 In-Situ Resource Processing System
Reserved

3.2.5.5 Wet Waste Processing System
Reserved

3.3 Material Storage

3.3.1 Atmosphere Management System

[ECLSS.xxx-PGM] O_2 Storage: The AMS shall provide storage for at least 120 kg of O_2 at 3447 kPa (500 psia).

Rationale: This is compliant with initial sizing estimates provided by Mars One and is sufficient O_2 to provide 30 days of oxygen for a crew of 4 with no resupply or complete one inflation of the 500 m^3 habitat.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Excess Habitat Atmosphere Storage: The AMS shall provide storage for at least 440 kg of Habitat Atmospheric Gas (Mixture or N_2, Ar, O_2, CO_2, H_2O, and trace contaminants) at 3447 kPa (500 psia).

Rationale: This is compliant with initial sizing estimates provided by Mars One and is sufficient Atmospheric Gas to complete one inflation of the 500 m^3 habitat.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] H_2 Storage: Reserved

Rationale: Although not part of the baseline, storage of H_2 (which is generated as a byproduct of O_2 production via water electrolysis) should be scarred in, as this useful resource could be utilized as the habitat evolves (e.g. as a fuel or input to the Sabatier process to recover water from CO_2).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Water Electrolyzer Feed Water Storage: The AMS shall provide storage for at least TBD kg of purified Water Electrolyzer feed water.

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

3.3.2 Water Management System

[ECLSS.xxx-PGM] Non-Potable Water Storage: The WMS shall provide storage for at least TBD kg of non-potable water.

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Potable Water Storage: The WMS shall provide storage for at least 1500 kg of potable water.

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

3.3.3 Thermal Control System

[ECLSS.xxx-PGM] Coolant Fluid Storage: The TCS shall provide storage for at least TBD kg of coolant fluid.

Rationale: A coolant fluid buffer (accumulator) is required for nominal operation of the pumped fluid loop (part of the active thermal control subsystem). It is noted that unlike other buffers in the ECLSS, the coolant fluid accumulator is not sized to provide any appreciable buffering in the system.

Verification: (IDAT) – TBD.

3.3.4 In-Situ Resource Processing System

[ECLSS.xxx-PGM] Non-Potable Water Storage: The ISRUS shall provide storage for at least TBD kg of non-potable water.

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Mars Atmosphere Storage: The ISRUS shall provide storage for at least TBD kg of Mars atmosphere at 3447 kPa (500 psia).

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

3.3.5 Wet Waste Processing System

[ECLSS.xxx-PGM] Wet Waste Storage: The WWPS shall provide storage for at least TBD kg of wet waste.

Rationale: Storage buffers are required throughout the ECLSS to accommodate nominal variations in production and consumption (e.g. diurnal and seasonal variation due to power availability or planned maintenance), and to accommodate and recover from contingency conditions (e.g. unplanned repair activities).

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Wet Waste Residual solids Storage: The WWPS shall provide storage for at least TBD kg of wet waste residual solids.

Rationale: Storage or residual wet waste solids is performed to provide inorganic and organic resources for future use.

Verification: (IDAT) – TBD.

3.4 Design & Construction

[ECLSS.xxx-PGM] Power Specification: The Habitat ECLSS shall be designed using the electrical standards defined in TBD.

Rationale: To ensure all system components are compatible, definition of voltages, currents, frequencies, etc. are all required. It is recommended that Mars One define the specifications to be used by the Mars Habitat and that all electrical components are designed per the standard (e.g. 110 vs 220V, AC/DC, 50 vs 60Hz, etc.)

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Maximum Electrical Power: The maximum electrical power supplied to the Habitat ECLSS shall be no greater than 35 kW over an 8 hour period (TBR).

Rationale: Based upon initial sizing estimates. Predicted maximum with a 10% minimum applied.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Minimum Electrical Power: The minimum electrical power supplied to the Habitat ECLSS shall be no less than 6 kW over a 12 hour period (TBR).

Rationale: Based upon initial sizing estimates. Predicted minimum with a 10% margin applied.

Verification: (IDAT) – TBD.

[ECLSS.xxx-PGM] Daily Electrical Energy Supply: The minimum electrical energy supplied to the Habitat ECLSS each day shall be no less than 392 kW-hr.

Rationale: Established based upon initial conceptual design. Predicted energy usage with a 10% margin applied

Verification: (IDAT) – TBD.

[ECLSS.xxx-SMA] Total Lifetime: The Habitat ECLSS shall operate with regular maintenance for a minimum of 10 years (TBR).

Rationale: Indefinite lifetime would be ideal (with maintenance but also impossible to test). However, there will be resupply of vital parts, during the bi-yearly deliveries of personnel. It is expected that there will be a ground test bed that will stay ahead of the cycles on Mars so to predict or experience latent failures prior to those on Mars.

Verification: (IDAT) – TBD.

[ECLSS.xxx-SMA] Mean Time to Repair (MTTR): The Habitat ECLSS repairs shall take no more time than 1 hr on average (TBR) based on access and replacement time.

Rationale: The MTTR is a key measurement of the maintainability of the ECLSS system and should be derived from total crew time allocated to maintenance and the proportion allocated to ECLSS vs. other system.

Verification: (IDAT) – TBD.

3.5 Interfaces

3.5.1 Human Interfaces

Reserved

3.5.2 System Interfaces

Reserved

3.5.3 Natural and Induced Environments

[ECLSS.xxx-PGM] Local Environment: The ECLSS shall be capable of operating on Mars in all seasons between the 40 and 45 deg north latitudes and at a pressure altitude not to exceed 600 kPa (TBR).

Rationale: The possible sites for the Martian outpost have not yet been defined, but current estimates place the Martian outpost between 40 and 45deg north latitude. The maximum pressure altitude is required to constrain the thermal and ISRU solutions (e.g. take advantage *of convective heat losses and establish worst-case pressure ratios for atmospheric compression).*

Verification: (IDAT) – TBD

[ECLSS.xxx-PGM] High Abrasion Dust: The ECLSS must be tolerant of or preclude contact with high abrasion dust.

Rationale: Based on experience during the Apollo Program, it was recognized that dust on the lunar surface can be especially harsh to equipment and poses a potential hazard to crewmembers, if carried inside the habitable volumes. It is believed that the Martian regolith will have the same potential effects. Compliance with this requirement is expected to be developed at the Habitat system-level. Approaches to meeting this requirement include, but are not limited to, manual cleaning operations, prevention of dust intrusion, dust immobilization, protective personal equipment, and design for reliability. Any systems that minimize dust contamination within the habitat will improve the life of the ECLSS architecture.

Verification: (IDAT) – TBD

3.6 Safety, Quality, and Mission Assurance

[ECLSS.xxx-SMA] Fault Tolerance: All ECLSS functionality shall be two fault tolerant (TBR) for catastrophic hazards and single fault tolerant (TBR) for critical hazards or shall receive approval for Design for Minimum Risk (DFMR).

Rationale: This establishes a minimum of two fault tolerance or DFMR to control catastrophic hazards and single fault tolerance to control critical hazards. It is anticipated that many functions and components of the suit will pursue DFMR.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Touch Temperatures: The ECLSS shall maintain touchable internal surface temperatures within the Habitat between 10 °C (50 °F) (TBR) and 45 °C (113 °F) (TBR).

Rationale: These values are derived from standard touch temperature limits necessary to prevent injury.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] No Preventative Maintenance Pre-Crew Arrival: The ECLSS shall require no preventive or limited life maintenance during the first two (2) years of remote operations prior to crew arrival.

Rationale: This requirement addresses the reality that the ECLSS must operate autonomously during the first two years on the surface as the habitat is uninhabited at that time. Activities associated with tele-robotic operation are not considered within the definition of maintenance for this requirement.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] Preventative Maintenance Post-Crew Arrival: Following crew arrival, the frequency of preventative or limited life maintenance shall be no less than three (3) months (TBR).

Rationale: This requirement addresses the desire to achieve system designs that are robust and that required only periodic maintenance. Even with this requirement, given the number of ECLSS systems, subsystems, and components, the crew will spend significant time maintaining the ECLSS. Activities associated with wipe down, and cleaning of reusable filters to ensure nominal operation are not considered within the definition of maintenance for this requirement.

Verification: (IDAT) – TBD

[ECLSS.xxx-SMA] SOW Standards: The following technical and process standards are derived from NASA's human spaceflight program and should be adhered unless alternative standards are approved by the chief engineer, program manager, and customer.

Rationale: This list represents a preliminary snapshot of known standards used by NASA and recognized as industry standard. Standards will continue to be used to ensure hazard and quality controls for critical systems. If there are preferred (company or industry) standards, some effort should be expended to ensure they are aligned with the intent of the NASA standards to ensure historical human spaceflight lessons learned are not lost.

- *NASA-STD-4003 Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment*
- *MIL-STD-461-F Requirements for Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*
- *JPR 8080.5 JSC Design and Procedural Standards*
- *NASA-STD-5019 Fracture Control Requirements for Spaceflight Hardware*
- *NASA-STD-6016 Standard Material and Process Requirements for Spacecraft*
- *NASA-STD-5017 Design and Development Requirements for Mechanisms*
- *JSC 65828, Structural Design Requirements and Factors of Safety for Space Flight Hardware*
- *JSC 65829, Loads and Structural Dynamics Requirements for Space Flight Hardware.*
- *JSC 28918EVA Design Requirements and Considerations*
- *NASA-STD-6016 Standard Materials and Processes Requirements for Spacecraft*
- *NPR 7150.2A NASA Software Engineering Requirements*
- *NASA-STD-8719.13B Software Safety Standard*
- *NASA-GB-8719.13 Software Safety Guidebook*
- *NASA-STD-5005C Standard for the Design and Fabrication of Ground Support Equipment*
- *ANSI/AIAA S-081A- Space Systems - Composite Overwrapped Pressure Vessels (COPVs) July 24, 2006*
- *AIAA Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components (S-080-1998e)*
- *AIAA S-120-2006 - Mass Properties Control for Space Systems*

Verification: (IDAT) – TBD

4 Functional Baseline Definition

The Habitat ECLSS is divided into five major systems, 1) Atmosphere Management System, 2) Water Management System, 3) Thermal Control System, 4) In-Situ Resource Processing System, and 5) Wet Waste Processing System.

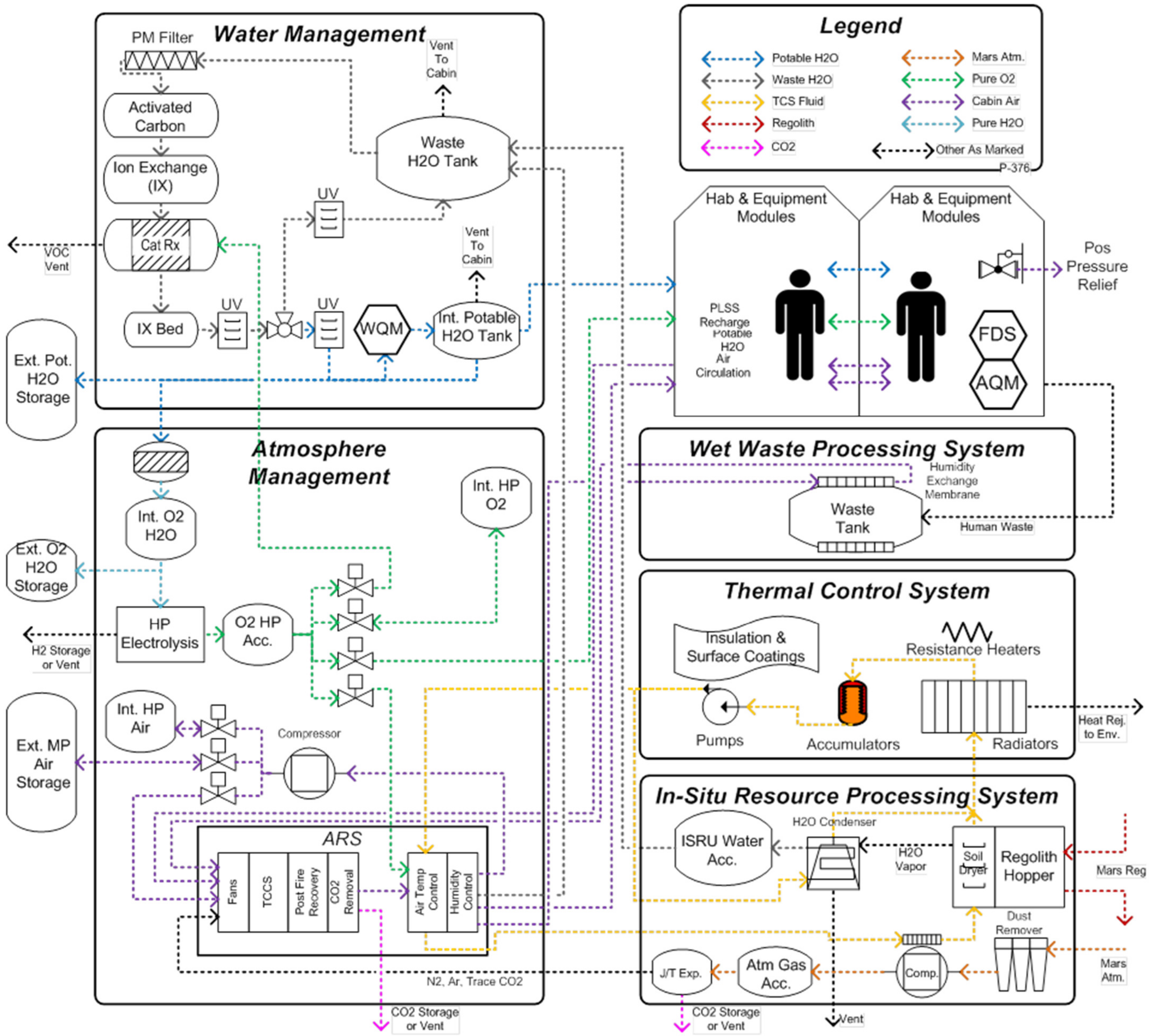

Figure 4: Mars One Habitat ECLSS Functional Layout.

4.1 Habitat ECLSS Overview

4.1.1 Atmosphere Management System

The Atmosphere Management System (AMS) provides a safe, thermally comfortable, and breathable atmosphere to the crew and all air-cooled electronics for the duration of the mission. The AMS also performs final purification and introduction of recovered ISRU-derived nitrogen and argon into the habitat and condenses, collects, and transports humidity condensate to the Water Management System. The three primary AMS subsystems – atmosphere revitalization, pressure control, and atmosphere monitoring – are described below.

4.1.1.1 Atmosphere Revitalization Subsystem (ARS)

The ARS provides the following life support functions:

- Atmosphere Circulation
- Atmosphere Particulate Control
- Trace Contaminant control
- Fire Detection and Notification
- Post-Fire Atmosphere Recovery
- Carbon Dioxide Control
- Oxygen Production
- Atmosphere Temperature and Humidity Control

4.1.1.1.1 Atmosphere Circulation

Brushless variable speed fans circulate the habitat air to provide adequate mixing, heat transport, and movement of the atmosphere through the various unit processes that revitalize the air. Habitat fan speeds are nominally manually controlled by the crew and only switched off during contingency operations (e.g. in the event of a fire).

4.1.1.1.2 Atmosphere Particulate Control

HEPA filters protected by lint/large particulate screens are located at all air inlets that are connected to any fan operating in the habitat. These filters remove particulate matter from the circulating air and protect downstream components and unit processes from contamination from the particulate matter. HEPA filter inlet screens are vacuumed regularly by the crew using portable hand-held vacuums to collect lint and detritus that collect on the inlet screens.

4.1.1.1.3 Trace Contaminant Control

The Trace Contaminant Control Assembly (TCCA) utilizes activated carbon and high temperature catalytic oxidation to remove airborne inorganic and organic contaminants generated by the crew and the habitat materials of construction (although the latter load will be minor provided a rigorous material of construction review and approval process is implemented and maintained). The TCCA is specifically designed and integrated to maximize airborne contaminant removal and to minimize transfer of these contaminants to the Water Management System.

4.1.1.1.4 Fire Detection and Notification

Fire detection consists of dedicated carbon monoxide sensors as well as particulate smoke detectors throughout the habitat that continuously monitor the habitat air circulating through the habitat along with additional CO measurements provided by the AQM. The habitat master computer is notified of any fire event. Although not part of the ECLSS, Paragon proposes that Mars One implement a fine water mist (FWM) fire suppression system in the form of portable fire extinguishers (PFE). It is envisioned that FWM PFEs would be employed to extinguish fires in open areas and behind avionics bays through fire ports. The implementation would be similar to that of the CO_2 PFE's currently employed on the ISS but will use water as a fire suppression agent instead of CO_2. The PFEs would be designed to be rechargeable by the crew.

4.1.1.1.5 Post-Fire Atmosphere Recovery

The Post Fire Atmosphere Recovery Subsystem (PFRS) provides functionality to recover to a safe, breathable habitat atmosphere following a fire event that has already been detected and extinguished. The PFRS provides for the removal of harmful post fire combustion products such as particulates, trace organic compounds, carbon monoxide and carbon dioxide without the need to depressurize the atmosphere and repressurize with stored gas. The subsystem utilizes the existing HEPA filters to remove 99.97% of air borne particulates 0.3 microns or greater in particle diameter. A cartridge inserted in the ARS air stream by the crew following a fire event utilizes granulated media to remove organic compounds and converts CO to CO_2. The precious metal catalyst used to complete the CO conversion to CO_2 was originally developed for NASA and is currently applied in facemasks utilized to protect the ISS crew during post-fire events. Generated CO_2 is removed by the existing CO_2 Removal Subsystem.

4.1.1.1.6 Carbon Dioxide Control

A Four Bed Molecular Sieve (4BMS) is utilized to remove metabolically produced carbon dioxide from the atmosphere. CO_2-laden air first passes through a desiccant bed to remove water and in the process is heated by the exothermic adsorption of the water by the desiccant. The hot dry CO_2-laden air then passes through a bed containing Zeolite that selectively removes carbon dioxide from the air, again via an exothermic adsorption process.

Hot, dry CO_2-free air then passes through another desiccant bed that had previously been utilized to remove water from the process stream. The hot, dry, CO_2-free air removes water from the second desiccant bed, is cooled in the process, and returns to the habitat. Just prior to the zeolite bed becoming saturated with CO_2, the inlet air is directed to the second now dry desiccant bed and then into new CO_2-free zeolite bed and out through the original, now saturated desiccant bed to continue removing CO_2 from the atmosphere. The first CO_2-laden zeolite bed is then heated up to drive off the CO_2 and a vacuum/pressure pump is utilized to transfer the CO_2 to a low pressure storage tank. From there the CO_2 can either be transferred to a Carbon Dioxide Reduction Processor or vented to the external environment.

The cyclical process is then continuously repeated to remove CO_2 from the habitat atmosphere and either vent it to the Martian atmosphere or pass it on to be used as a commodity such as compressed air cleaning to be used by the crew prior to reentry into the Habitat. Future inclusion of subsystems that recover water and/or O_2 (e.g. Sabatier reactor or Solid Oxide Electrolysis) could also make use of concentrated CO_2 although this functionality is not contemplated currently.

4.1.1.1.7 Oxygen Production

The Oxygen Production Assembly (OPA) receives potable water from the Water Management System, performs additional purification, and electrolyzes it to H_2 and O_2. O_2 is mixed with the air stream, fed to other processes requiring pure O_2, or stored. The OPA is operated at moderate pressure (1000 psia) to produce gas that can be routed directly into storage vessels without the need for further compression. This system is considered safer and more reliable compared to post-electrolysis oxygen compression. H_2 is currently routed overboard but may be considered as valuable commodity for hydrogen based material or as a spray line for removing dust on EVA suits prior to reentry. In addition, future ECLSS upgrades that include physio-chemical CO_2 recycling would also make use of recovered H_2.

4.1.1.1.8 Atmosphere Temperature and Humidity Control

Warm, humid habitat air is circulated across a condensing heat exchanger to cool the air and condense the water vapor into a liquid. The flow of active thermal control system (ATCS)-supplied chilled coolant through a liquid-gas heat exchanger is regulated by a bypass valve to affect the required air temperature control. The non-potable condensed water is collected and transferred to the Water Management system for further processing. The cool dry air is returned to the habitat atmosphere. It is expected that 99% of all condensate will be recovered.

4.1.1.2 Pressure Control Subsystem (PCS)

The PCS provides the following atmosphere life support functions:

- Pressurized Gas Storage
- Absolute Pressure Control
- Oxygen Partial Pressure Control
- Positive Pressure Relief

4.1.1.2.1 Pressurized Gas Storage

Primary atmospheric constituent N_2/Ar and O_2 are stored at moderate pressure (500-1000 psia). Sufficient gas is contained to accommodate all contemplated contingency and planned scenarios (e.g. nominal leakage and planned consumption). Detailed system design and trades will be completed to determine the optimum storage pressure, location, and construction of the gas accumulators. Consideration will be given to the utilization of externally located deployable and inflatable accumulators. It is also expected that the system-level solution should consider maximizing storage of atmospheric gasses to increase robustness and long-term reliability.

4.1.1.2.2 Absolute Pressure Control

Under nominal conditions, valve sets consisting of pressure regulators and automated and manual valves introduce ISRU-derived N_2/Ar into habitat to resupply losses due to nominal leakage and operation of the habitat airlocks. In the event of contingency conditions, additional valve sets introduce stored N_2/Ar/O_2into the habitat as directed by the habitat master computer or the crew to maintain the habitat pressure between 66.9 kPa (9.7 psia) and 70.33 kPa (10.2 psi) (TBR).

4.1.1.2.3 Oxygen Partial Pressure Control

Valve sets consisting of pressure regulators and automated and manual valves allow the introduction of additional O_2 into the habitat as directed by the flight computer or the crew to maintain the habitat oxygen partial pressure between 17.2 kPa (2.5 psi) (TBR) and 20.0 kPa (2.9 psi).

4.1.1.2.4 Positive Pressure Relief

This functionality is provided to prevent structural failures due to over-pressure of the habitat volumes. Over-pressure could result from the inadvertent introduction of stored primary atmospheric constituent gasses (i.e. N_2/Ar, and O_2) or overheating of the habitat.

4.1.1.3 Atmosphere Quality Monitor

The Atmosphere Quality Monitor (AQM) monitors critical atmospheric gaseous constituents and other parameters important the maintenance of the habitat atmosphere. A mass spectrometer continuously monitors O_2, N_2, Ar, CO_2, H_2, CO, and water vapor. Pressure transducers also monitor habitat absolute pressure and gas storage tank pressures. Finally, air temperature and air flow sensors measure these parameters to ensure temperature control and habitat air mixing are maintained. All data is provided to the habitat master computer and utilized to monitor ARS performance and effect control.

4.1.2 Water Management System

The Water Management System (WMS) receives non-potable humidity condensate and water produced by the ISRU System and produces potable water that is utilized by the crew for drinking, food preparation, and hygiene. It also supplies purified water to the Air Management Systems Oxygen Production Assembly which electrolyzes the water into oxygen and hydrogen.

4.1.2.1 Primary Water Processor

The Primary Water Processor receives water from the air management system that was condensed from the habitat atmosphere. It also receives potentially contaminated wastewater from the ISRU subsystem. Wastewater from these sources is collected and temporarily stored in a non-potable water tank. Entrained air is returned to the habitat atmosphere and the wastewater is pumped through a particulate filtration bed, an activated carbon bed, and an ion exchange bed to remove all inorganic contaminants and a majority of the organic contaminants.

The wastewater is then passed through an aqueous phase catalytic reactor (which is also supplied with a trace amount of pressurized oxygen) that oxidizes remaining organic contaminants. Residual contaminant volatile vapors are vented to the external environment. A final ion exchange bed removes residual oxidation products and the conductivity of the product water is measured to verify cleanliness. Product water can be redirected to the non-potable water tank for reprocessing if it does not meet potable water quality requirements or directed to the potable water tank if it does. Three 254 nm UV disinfection lamps (just downstream of the final IX bed, on the return line to the wastewater tank, and on the delivery line to the potable water tank minimizes the risk of microbial contamination of the potable water tank. Potable water is then distributed as required for drinking, food processing, hygiene, and oxygen production. Additional point-of-use 254 nm UV disinfection lamps are utilized at each potable water distribution point to inhibit microbial activity. Excess potable water will be stored to the maximum extent practical. As with atmospheric gas storage, detailed design and trades will be conducted to determine the maximum practical size and location of the potable water accumulators.

4.1.3 Thermal Control System

The Thermal Control System (TCS) includes both active components such as liquid cooling loops and passive components such as insulation and surface coatings to control temperatures throughout the habitat. As a general rule *everything* works best within specific temperature ranges. The purpose of a TCS is to effectively keep everything within those ranges by passive means (insulation, etc.) if possible and active means (cooling loop, heaters, etc.) when necessary.

The primary method of cooling will be air convection within the pressurized habitat volume. The primary internal sources of heat will be the crew and computers or other devices that are designed for effective air cooling. The primary TCS fluid loop routes to the “Air Temp control” heat exchanger where the fluid absorbs heat from the circulated air to provide temperature control within the habitat. Notionally, this heat can then be used to warm the Martian Regolith to release water and other volatiles for capture. Finally any remaining heat is transported to radiators or buried heat transfer pipes located external to the habitat and rejected to the external environment. Another loop of TCS fluid provides cooling to the “H_2O Condenser” within the In-Situ Resource Processing System where it is used to condense water vapors being harvested from Martian regolith. Liquid cooling is significantly more mass and power efficient than air cooling, but the crew and some components such as laptop computers are just not compatible with fixed liquid cooling loops. When working at the design level, the actual mix of components chosen by Mars One will determine the sufficient mix of liquid and air cooling.

Other important TCS components include electrical resistance heaters for remotely located components and bulkheads (prevents condensation) and also insulation and optical surface coatings on external habitat surfaces.

The TCS must be flexible enough to handle variable waste heat loads and different external thermal environments (i.e. diurnal changes as well as seasonal variations). Waste heat generation will also change with system operational loads and crew activity level.

4.1.4 In-Situ Resource Processing System

The *in-situ* Resource Processing System (ISRPS) performs two primary functions. The first function is to extract water from externally supplied Martian regolith and/or water ice, and the second is to extract usable gasses from the Martian atmosphere for use in the Atmosphere Management System.

4.1.4.1.1 In-Situ Water Processor

The driving requirement for sizing the ISRU Water Processor (ISWP) is the post-crew 9.0 kg/day water production rate. This system relies on an external and Non-ECLSS Regolith Supply and Return System (RSRS) to supply water-ice laden regolith and to dispose of water depleted regolith. An ISWP hopper is opened to the external environment and filled with regolith and then closed and pressurized for processing. In batches, the regolith is heated to vaporize the water from the regolith, the water condensed in a purified--but non potable--form, and then transferred to the Water Management System for purification to potable water. The dried Martian regolith would then be removed from the hopper and returned to the external environment and the next batch introduced. The cyclical process is then repeated. Ideally this process will be driven by waste heat, perhaps that generated by the compressor of the ISRU Gas Processor. Furthermore, detailed design work is needed to quantify heat losses due to the heat capacity of the Martian regolith and determine heat recovery steps if advantageous.

Given the highly oxidized nature of the Martian environment, it is likely that superoxides will be encountered that could react in the presence of liquid water and release O_2 during the water removal process. Upon further evaluation, this effect should either be avoided by design, or used to the system’s advantage for supplemental O_2 production.

A trade should be conducted to determine if lyophilization (freeze-drying) would offer advantages over ice melting and evaporation to mitigate potential adverse effects such as the presence of superoxide in the regolith.

4.1.4.1.2 In-Situ Gas Processor

Martian ambient atmosphere is filtered to remove particulates and compressed to multiple atmospheres to allow Joule-Thomson cooling to create liquid or solid CO_2 enabling the efficient separation of trace N_2 (~2.7%) and Ar (~1.6%) from the predominately CO_2 (~95.3%) Martian atmosphere. This separated gas, now at the colony internal pressure, is transferred to the Air Management System where it is injected upstream of the air revitalization assembly (ARS) to be processed along with the substantially larger stream of recirculating habitat air. In this fashion the existing ARS CO_2 removal functions are used to remove residual CO_2 from the captured Martian atmosphere without the need for additional equipment.

The In-Situ Gas Processor (ISGP) will generate heat from the compression process as well as copious quantities of CO_2 liquid and/or ice. The waste heat is notionally used to drive the ISRU Water Processor and it is anticipated that some future uses for the CO_2 product can be found such as alternate oxygen generation, and CO fuel production through the Reverse Water Gas Shift (RWGS) process. CO_2 can also be used as a coolant for EVA, as a purge gas to rid the airlock, solar panels, and other equipment of dust, and even as a source of motive power in an expansion cycle engine to power rovers or drive machinery.

A trade should be conducted to determine if membrane separation, pressure swing adsorption, cryogenic cooling technologies, or some combination thereof would offer advantages over Joule-Thomson cooling alone or in combination with it.

4.1.5 Wet Waste Processing System

The Wet Waste Processing System (WWPS) serves to isolate human wet waste (principally urine, feces, food waste and hygiene waste) and recover water using a low-tech approach. Rather than introduce the significant complications of direct urine and fecal matter processing, this conceptual approach is one of a passive drying system that will extract water from the human waste while maintaining isolation from other systems. This is accomplished by using a humidity exchange membrane. Dry habitat air blowing across one side of the membrane will pull humidity from the warm wet side, along with a limited quantity of known contaminants. Heat input on the waste side drives the release of water vapor from the wet waste. The water vapor laden air is then returned to the AMS where trace contaminants are removed and water is condensed and transported to the WMS for further processing. The resultant residual wet waste (sludge) will be stored for eventual future use as a source of organic and inorganic compounds.

4.2 ECLSS Sizing Summary for Nominal Post-Crew Arrival Operations

The following ECLSS sizing summary information is provided for nominal operations post-crew arrival. These figures assume that all contingencies will either be handled by supplies produced and stored prior to crew arrival, by gradual replenishment of stores by operating at the maximum production rates or by the redundant ECLSS units that will arrive with each crew. Future Concept of Operations analysis will quantify short-term and long-term contingency operating mode requirements. Future analysis may dictate reassessing nominal performance requirements and these sizing estimates.

4.2.1 Nominal Oxygen Production

All oxygen is generated by the electrolysis of ISRU-supplied water. A summary of daily oxygen supply needs is provided below along with the levied oxygen production requirement:

Table 3: Nominal oxygen production

Oxygen Use	1 Crew O_2 (kg/day)	4 Crew O_2 (kg/day)
Crew metabolism	0.89	3.56
O_2 Nominal Daily Leakage (0.5%)		0.57
O_2 Daily Airlock Losses [1]		0.91
Miscellaneous [2]		0.50
Total:	0.89	5.53
Levied Requirement:		6.00

[1] *This is a conservative estimate as it currently assumes 4 airlock cycles per day and 1 m^3 of atmosphere lost per cycle. The number of cycles is expected to be reduced. In addition, the airlock from only one of the redundant habitats would be utilized. Thus actual airlock losses are expected to be less than half of the current estimate.*

[2] Estimated at 10% of the daily oxygen use (e.g. stored O_2 replenishment or unplanned use, etc.)

4.2.2 Nominal Pressurant Gas Production

All pressurant gas (N_2/Ar) is supplied by the ISRU System and extracted from the Martian atmosphere. A summary of daily pressurant gas supply needs is provided below along with the levied pressurant gas requirement. It is noted that there is significant margin between the levied requirement (original estimate supplied by Mars One) and the predicted daily pressurant gas production rate. The variation would be even greater if reductions in airlock cycling losses are realized. An opportunity exists to quantify the pros and cons of reducing the requirement, increasing pressurant gas storage, or a combination of the two.

Table 4: Nominal pressurant Gas Production

Pressurant Gas Use	N_2/Ar (kg/day)
Nominal Daily Leakage (0.5%)	1.53
Daily Airlock Losses [1]	2.44
Miscellaneous [2]	0.40
Total:	4.36
Levied Requirement:	7.00

[1] *This is a conservative estimate as it currently assumes 4 airlock cycles per day and 1 m^3 of atmosphere lost per cycle. The number of cycles is expected to be reduced. In addition, the airlock from only one of the redundant habitats would be utilized. Thus actual airlock losses are expected to be less than half of the current estimate.*

[2] *Estimated at 10% of the daily pressurant gas use.*

4.2.3 Nominal Potable Water Use, Recycling, and ISRU Resupply

Potable water needs are met by a combination of recycling and introduction of ISRU-supplied water. A summary of the daily potable water needs is provided below along with levied requirements for potable water production and ISRU-supplied water. It is noted that the levied requirement of 9 kg/day is much lower than the original estimate of 100 kg/day supplied by Mars One. This difference was significant enough that Paragon recommends the lower requirement unless further discussions provide adequate rationale for increasing the requirement.

Table 5: Nominal potable water needs, recycled, and resupplied via ISRU

Water Use	1 Crew (kg/day)	4 Crew (kg/day)	% Recycled	Recycled (kg/day)	ISRU Supplied (kg/day)
Shower [1]	4.00	16.00	98%	15.68	0.32
Oral Hygiene	0.37	1.48	98%	1.45	0.03
Urine Flush	0.30	1.20	75%	0.90	0.30
Laundry [1]	4.00	16.00	98%	15.68	0.32
Consumption/food preparation	3.91	15.64	75%	11.73	3.91
Metabolic O_2 Production[2]	1.00	4.00	75%	3.00	1.00
Nominal Leak O_2 Makeup [3]		0.64	0%	0.00	0.64
Airlock Cycling O_2 Makeup [4]		1.02	0%	0.00	1.02
Miscellaneous [5]	1.36	5.43	75%	4.07	1.36
Total:	14.94	61.49	85% [6]	52.51	8.89
Levied requirement		62.00			9.00

[1] Shower and laundry water could potentially be reduced to operate in a contingency water saving mode should one of the two ECLSS modules become unavailable. However that is not assumed for this initial conceptual design.
[2] This is the water that must be electrolyzed to generate the requisite metabolic O_2
[3] Assumption is nominal atmospheric leakage is 0.5%/day and this is the water that must be electrolyzed to generate makeup O_2
[4] Assumption is 4 airlock cycles per day, airlock is 10 m^3 and 10% of volume is lost per cycle. This is the water that must be electrolyzed to generate makeup O_2
[5] Estimated at 10% of the daily water use (e.g. water spills, unanticipated uses, etc.)
[6] Average water recovery

4.2.4 Nominal Maximum and Minimum Heat Rejection

Nominal maximum and minimum heat rejection extremes are dependent upon available electrical power and they are summarized in the tables below:

Table 6: Nominal maximum heat rejection on the longest day of the year

Parameter	Units	Value
Supplied electrical power on longest day from solar arrays and stored battery power	kW-hr	1070.0
Estimated electrical power dissipated within the habitat	%	75%
Electrical energy rejected as heat	kW-hr	803.0
Crew sensible metabolic load	kW-hr	9.3
Total sensible heat load	kW-hr	812.0
Levied Requirement:	kW-hr	900.0
Latent water load [1]	kW-hr	35.1
Levied Requirement:	kW-hr	40
Total heat load:	kW-hr	837.6
Levied Requirement:	kW-hr	940.0
Margin:	kW-hr	102.4
Margin	%	12
Average heat rejection over 24 hours, kW (not corrected for Mars day duration)	kW	34.8
Peak Heat Load - Assumed 20% > than average (not corrected for Mars day duration)	kW	41.7
Assumed peak load duration	hr	2

[1] Water condensed on cabin air heat exchanger (sources include crew metabolic water and water produced by the Wet Waste Processing Subsystem).

Table 7: Nominal minimum heat rejection on the shortest day of the year

Parameter	Units	Value
Supplied electrical power on shortest day from solar arrays and stored battery power	kW-hr	267.0
Estimated electrical power dissipated within the habitat	%	75%
Electrical energy rejected as heat	kW-hr	200.3
Crew sensible metabolic load	kW-hr	9.3
Total sensible heat load	kW-hr	209.6
Levied Requirement:	kW-hr	900.0
Latent water load [1]	kW-hr	35.1
Levied Requirement:	kW-hr	40
Total heat load:	kW-hr	235.4
Levied Requirement:	kW-hr	940.0
Margin:	kW-hr	704.6
Margin	%	299
Average heat rejection over 24 hours, kW (not corrected for Mars day duration)	kW	9.8
Peak Heat Load - Assumed 20% > than average (not corrected for Mars day duration)	kW	11.8
Assumed peak load duration	hr	2

[1] Water condensed on cabin air heat exchanger (sources include crew metabolic water and water produced by the Wet Waste Processing Subsystem).

4.2.5 Nominal ISRU Regolith Throughput

Assuming water content of 5% (Mars One Assumption), a requirement to generate 9 kg/day of non-potable water, and adding 10% margin, the estimated daily throughput of Mars regolith is 198 kg.

4.2.6 Nominal ISRU Mars Atmosphere Throughput

Table 8: Predicted throughput of Martian atmosphere to extract N_2/Ar, if CO_2 is extracted in solid form as dry ice.

Parameter	Units	Value
N2/Ar generation each day	kg	7.0
Mass fraction of Ar and N2 in Martian atmosphere[1]		0.030
Quantity of Martian atmosphere to process each day	kg	237.5
Mass fraction of CO_2in Martian atmosphere[1]		0.969
CO_2frozen out of the Martian atmosphere each day	kg	230.2
CO_2enthalpy of deposition	kJ/kg	571
Cooling required to freeze CO_2	kJ	131419
Cooling required to freeze CO_2	kW-hr	36.5
Cooling power required running 15 hours per day	kW	2.6
Estimated cryo-cooler electrical power [2]	kW	22
Average daily cryo-cooler electrical power [3]	kW	13.8

[1] Noted that this is mass fraction, not molar fraction

[2] Estimated from commercially available cryocooler operating 15 hours per day

[3] Average electrical power over a 24 hour day (not corrected for Mars day duration)

Table 9: Predicted throughput of Martian atmosphere to extract N_2/Ar if CO_2 is extracted as liquid CO_2.

Parameter	Units	Value
N2/Ar generation each day	kg	7.0
Mass fraction of Ar and N2 in Martian atmosphere [1]		0.030
Quantity of Martian atmosphere to process each day	kg	237.5
Mass fraction of CO_2 in Martian atmosphere [1]		0.969
CO_2 frozen out of the Martian atmosphere each day	kg	230.2
CO_2 enthalpy of formation[2]	kJ/kg	150
Cooling required to liquefy CO_2	kJ	34523
Cooling required to liquefy CO_2	kW-hr	9.6
Cooling power required running 5 hours per day	kW	1.9
Estimated Cryo-cooler electrical power [3]	kW	22
Average daily cryo-cooler electrical power [4]	kW	4.6

[1] *Noted that this is mass fraction, not molar fraction*

[2] *CO_2 Enthalpy of formation to go from a saturated vapor to a saturated liquid*

[3] *Estimated from commercially available cryocooler operating 5 hours per day*

[4] *Average electrical power over a 24 hour day* (not corrected for Mars day duration)

4.3 Surface Habitat ECLSS Mass, Power, and Volume Estimates

Table 10 summarizes the mass, power, and volume of the conceptual Habitat ECLSS to complete pre-crew arrival operations and 2 years of post-crew arrival operations. Figure 5 shows a preliminary electrical power profile (not corrected for difference between Earth and Mars day duration). This data represents a very preliminary notional estimate. It is noted that the power profile is representative of the worst-case expected in terms of diurnal variation and is driven by the assumption that the ISRU function must be completed in 8 hours. This in turn is due to the minimum electrical energy available on the shortest daylight day of the year (8.5 hours) that was supplied by Mars One.

It is noted that the ECLSS daily electrical energy requirement shown in Table 10 exceeds the electrical energy production on the shortest day of the year shown in Table 7 (356 kW-hr versus 267 kW-hr). This implies operational adjustments (e.g. relying on storage buffers of water, atmospheric gasses, and oxygen) will need to be made in order to reduce the ECLSS electrical power requirement during short-day operations. Alternatively, Mars One could increase the size of the solar electrical power production system to meet the ECLSS and overall habitat electrical power requirement. Follow-on work is required to determine the system cost of increasing the size of metabolic consumable buffers to accommodate this transient event versus the system cost of increasing the size of the solar electrical power production system.

Table 10: Estimated mass, power, and volume for the Mars One Habitat ECLSS. Mass and volume estimates cover 2 years pre-crew arrival and 2 years post-crew arrival operations.

System / Subsystem	Mass (kg) [1, 2]	Vol (m^3)	Avg Power (kW)	Daily Energy (kW-hr)	Run Time (hr) [3]	Peak Power (kW)
Atmosphere Management	**2730**	**16.77**	**4.8**	**114.7**	N/A	**4.8**
Pressure Control	91	0.12	0.1	1.8	24	0.1
Air Revitalization	1914	2.97	4.7	112.8	24	4.7
Gas Storage	644	13.40	0.0	0.0	24	0.0
Fire Detection & Atmosphere Recovery	80	0.28	0.0	0.0	24	0.0
Water Management	**1540**	**5.62**	**1.1**	**27.2**	N/A	**2.2**
Potable Water Storage	461	1.65	0.0	0.0	24	0.0
Primary Water Processor	1000	3.95	1.1	26.5	12	2.2
Water Quality Monitor	79	0.03	0.0	0.7	24	0.0
Thermal Control	**1085**	**0.40**	**0.5**	**12.4**	N/A	**0.5**
Active Heat Collection	181	0.12	0.0	0.0	24	0.0
Active Heat Transport	374	0.11	0.5	12.4	24	0.5
Active Heat Rejection	530	0.16	0.0	0.0	24	0.0
Passive Thermal Control [4]	0	0.00	0.0	0.0	24	0.0
In-Situ Resource Processing	**2200**	**3.90**	**6.9**	**165.6**	8	20.7
Wet Waste Processing	**208**	**2.50**	**1.5**	**36.0**	12	3.0
Packaging and Installation Factors [5]	**776**	**5.84**	-	-	-	-
ECLSS Total:	**8540**	**35.03**	**14.8**	**355.9**	-	**31.2**
ECLSS Lander Totals [6]:	**7434**	**19.98**	**14.8**	**355.9**	-	**31.2**

[1] Dry system mass – does not include any water, N_2/Ar, or O_2 produced on the surface

[2] Mass growth allowance factor applied based upon product design maturity as defined in "Mass Properties Control for Space Systems"(AIAA S-120-2006).

[3] Run times are Paragon estimates. Driver is ISRU run time of only 8 hours due to minimum electrical energy day estimate supplied by Mars One.

[4] Mass and volume of passive thermal control features assumed to be included with primary structures

[5] Packaging and installation factors are estimated at 10% for mass and 20% for volume

[6] Assumed that gas and potable water storage tanks are soft-goods based and integrated with the inflatable habitat (not the ECLSS lander).

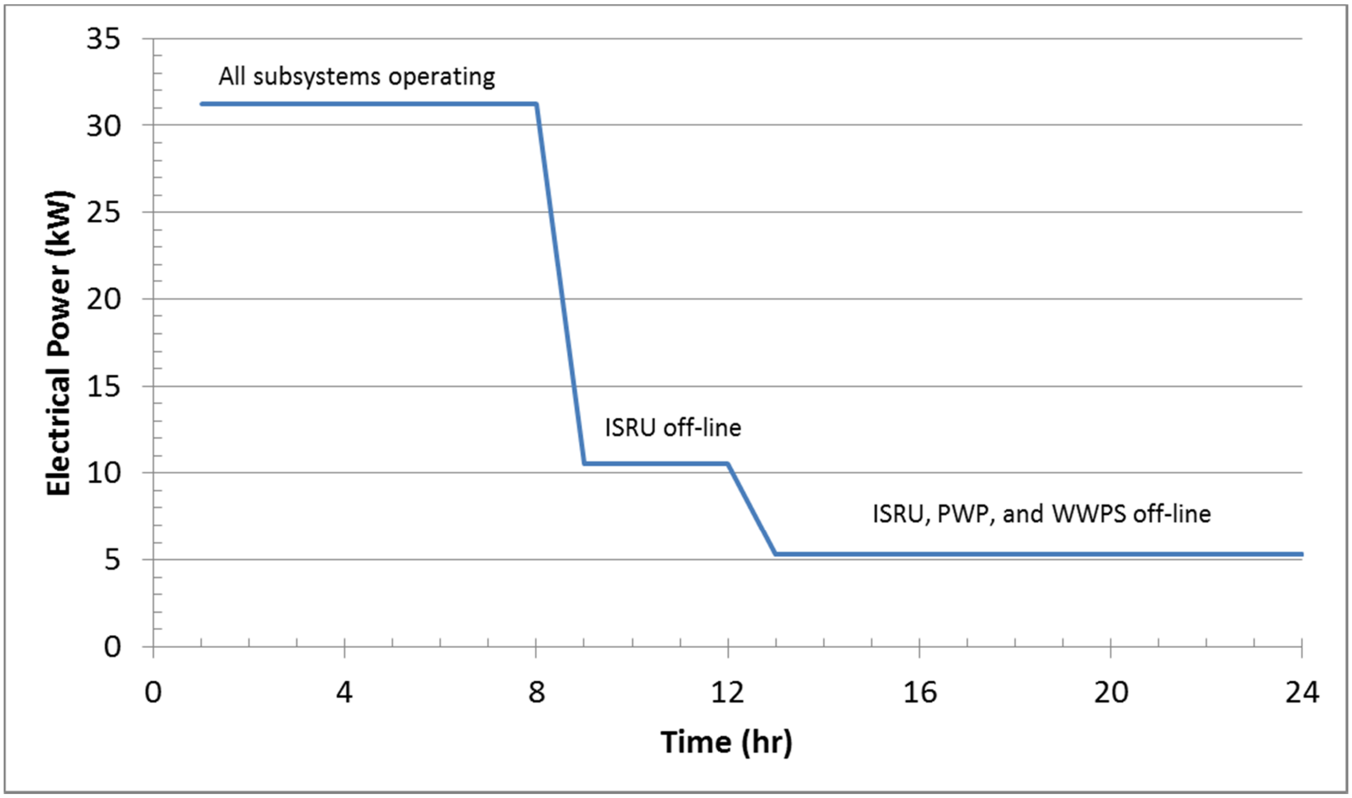

Figure 5: Conceptual electrical power profile assuming the subsystem operating times shown in Table 10 (and not corrected for actual Mars day duration).

5 Risk and Opportunity Management

5.1 Identified Risks

5.1.1 Useful Service Life

Due to the unique nature of the mission, a minimum initial two-year service life without maintenance or repair must be established for the Habitat ECLSS at the system level. This is necessary as the habitat ECLSS operates autonomously for two years prior to the arrival of the first crew and successful completion of its function (i.e. generation of a breathable atmosphere and stores of oxygen and water) is required before Mars One commits to launching the first crew. Post-crew landing service life will have to account for the fact that replacement parts will require significantly better logistical management due to the time and distance required for transport. As such, pre-crew service life needs to be higher than any previously developed habitat ECLSS.

5.1.2 Design for Field Maintenance and Repair

The ELCSS must be maintainable by a limited crew with limited supply of tools and equipment as resupply will be costly and infrequent. Design for simplicity, reliability, and ruggedness is required. The first objective should be to reduce the need for maintenance; second objective should be to make maintenance easy/quick; and third objective should be to minimize limited life items that require replacement. Alternatively, design robustness to accommodate 3D printers and other local manufacturing technologies may mitigate logistic requirements.

5.1.3 Hardware, Spares, and Consumables Mass

Typical of all launch programs, minimization of launched mass is critical to meeting transportation cost constraints. As a result, the drive to reduce the overall mass of the ECLSS will tend to increase system complexity and development cost. A trade on launch costs versus ECLSS development costs must be conducted to arrive at an overall minimum cost to the program. The cost and capabilities of the transportation systems required to accurately deliver hardware from Earth to Mars will drive the overall maximum allowable mass of the ECLSS hardware, spares, and consumables.

5.1.4 Hardware, Spares, and Consumables Volume

Similar to mass, minimizing the volume of the ECLSS hardware while maintaining overall robustness, serviceability, and maintainability, will drive increases in complexity and cost of the system if a balance is not reached with volume provided during transportation and surface operations.

Although not part of the ECLSS, it is noted that the Mars One mission will benefit from one of the advantages of inflatable structures such as accumulators or habitable volumes, namely because they can be compactly stowed during launch, transit, and landing, and then deployed only when they are required for surface operations.

5.1.5 Nominal Habitat Atmospheric Pressure

The absolute pressure of the habitat will influence the workload of the ECLSS electromechanical components such as pumps, tanks, fans, compressors, etc. and can drive the design of structural components. Choice of habitat pressure is a multivariable trade space, highly linked with system design variables such as spacesuit pressure, crew physiological requirements, flammability limits, and even future bioregenerative life support requirements. For example, a lower atmospheric pressure may be ideal for EVA pre-breath and reducing the habitat leak rate, but it may unacceptably minimize volumetric buffer of toxic gases or trace contaminates, thus requiring higher processing flow rates. Hearing may also be degraded to an unacceptable level at a lower absolute pressure within the habitat.

5.1.6 Habitat Atmosphere Leak Detection, Isolation, and Repair

Rapid loss of habitat atmospheric pressure to a contingency leak is considered the greatest acute risks to the crew. Although not part of the ECLSS, leak detection, isolation, and repair systems and processes that rapidly mitigate contingency leaks must be given priority by the Mars One program.

5.1.7 Water Availability and Quality

Water is critical to the survival of the crew and the Mars One Architecture assumes includes harvesting water from Martian regolith via ISRU. The purity of Martian-derived water is not known with absolute certainty thus the processing required to meet human potability and water electrolysis purity requirements will require a conservative approach to ensure safety of the crew and equipment.

5.1.8 Dust/Contamination Mitigation

Given the need to conduct EVAs, crew ingress and egress from the habitat will inevitably introduce Martian dust within the habitat. The ECLSS architecture will need to be designed to handle the additional contamination. Collaboration with the habitat layout through use of pre-dusting and staged airlocks may mitigate contamination while minimizing atmospheric pressure loss.

5.1.9 ISRU Interface with External Regolith Supply and Return System

Routine and continuous supply of water-laden regolith to the In-Situ Resource Utilization (ISRU) Subsystem (ISRUS) and the return of water-depleted regolith to the external environment is critical to mission success as externally supplied water is the sole source of all water entering the Surface Habitat. This water is used to maintain potable water levels and produce oxygen. Early development of the Habitat ECLSS ISRUS as well as the external Regolith Supply and Return System is warranted as the interface must deal with abrasive solid contaminants and frozen water. And it must operate continuously without any human servicing for the first two years of operation.

5.1.10 ISRU Interface with Martian Atmosphere

Routine and continuous supply of Martian Atmosphere to the In-Situ Resource Utilization (ISRU) Subsystem (ISRUS) is critical to mission success as the Martian atmosphere is the sole source of pressurant gas used to generate and then maintain the Surface Habitat atmosphere. Early development of the ISRUS-Atmosphere interface is warranted as the interface must deal with abrasive solid contaminants (i.e. blowing dust), and it must operate continuously without any human servicing for the first two years of operation.

5.1.11 Electrical Power for ISRU-supplied Pressurant Gas

Initial sizing calculations indicate the ISRU electrical power requirement dominates over other ECLSS functions. The energy required to compress the Martian atmosphere and separate pressurant gas (N_2/Ar) from the bulk CO_2 via the baseline cryo-separation is a primary driver within the ISRU System. Further development and trades should be conducted to explore the introduction of existing mature technologies such as membrane-based gas separation. A trade should be conducted to determine if membrane separation, pressure swing adsorption, cryogenic cooling technologies, or some combination thereof would offer advantages over Joule-Thomson cooling alone or in conjunction with it. Such technologies may augment or replace and lead to reductions in electrical power and an increase in reliability.

5.1.12 Electrical Power Availability

As previously discussed in Section 2.4, seasonal variations in available electrical power may cause significant increases in ECLSS peak production rates and the size of storage buffers. A trade should be conducted to determine the optimum system-level solution (i.e. the right-sizing of storage buffers and the solar electrical power system).

5.1.13 Storage Tank Location

Storage of ECLSS consumables (principally O_2, N_2/Ar, and potable water) should be as large as possible to maximize the opportunity to build up surplus consumables. Coupled with the previous risk, these buffer volumes may need to grow even larger to accommodate seasonal variations in available power. The predicted size of the tanks exceeds available volume in the ECLSS lander and may exceed available volume in the deployable habitat (depending on the needs of other habitat systems). Consideration should be given to integrating the storage tanks into the Inflatable Habitat pressure vessel walls. Consideration should also be given to determining the optimum level of redundant storage tanks.

5.2 Opportunities to Reduce Risk

5.2.1 Early Materials Compatibility Testing

To reduce risks on the program, early robotic missions should include material compatibility testing to ensure that predicted behaviors match observed behaviors.

5.2.2 Inclusion of Dissimilar Oxygen Production Methods

Inclusion of dissimilar methods for production of metabolically required O_2 should be considered. For example, inclusion of a Sabatier Reactor that combines waste H_2 from water electrolysis with CO_2 to generate water (that is then electrolyzed to produce O_2) adds system complexity and mass, but it increases options for generating/conserving this critical metabolic consumable. More advanced CO_2 reduction via processes such as the Bosch reaction or solid oxide electrolysis could also be considered, although more technology development would be required to develop operational systems.

5.2.3 Seals

One of the biggest unknowns for system sizing is currently the assumed atmospheric leak rate. Current system sizing assumes 0.05%/day. There is an opportunity that if the passageways and seals are design in such a way that the system provides a tighter sealing system, leak rates could be reduced. This could be accomplished through a sealing system that once activated; a bonded or welded seal is generated.

5.2.4 Minimization of ISRU Throughput

Post-Crew operations require the continuous supply of N_2/Ar and water from the local Mars environment. Minimizing the daily supply rate of these consumables reduces wear on the ISPS, electrical energy requirements, and crew operations. Trades and a sensitivity analysis should be conducted to determine the effects of increasing internal water recovery rates, decreasing planned atmospheric leakage (e.g. reducing the number of airlock cycles), and reducing the daily supply of non-metabolic water. Lower water and N_2/Ar supply rates may lead to reductions in ECLSS mass and volume and/or increases in robustness and the ability to recover from unplanned contingency situations.

5.2.5 Early adoption of In-Situ Manufacturing (Additive Manufacturing)

One technology area that has the potential to greatly reduce cost and risk, and might be considered valuable for Mars One outpost, is early adoption of Additive Manufacturing (hereafter called 3D printing). Recognizing that there is a finite amount of mass that can be transported to the Martian surface, it would be impossible to bring spares of all parts to account for any potential contingency or needed repair. Given recent advances in existing 3D printing technology, it is possible that the quantity of supplied spares could be significantly reduced; it is expected that many parts could be manufactured in-situ and only as the needs arise. The crew would need to bring with them the 3D printing machines and raw materials, and if the need arises for a replacement item, a spare nut or bolt, a specialty tool, etc. then they could “manufacture” it as needed. This eliminates the need to prepare the crewmembers for every possible contingency, and also eliminates the concern that they will get to the surface of Mars and realize they desperately need something that they don’t have.

It is expected that many ECLSS components could be manufactured with 3D printing. This technology could significantly reduce the need for serviceability and long service life items.

5.2.6 Early Water Processing Demonstration Plant

To minimize the impact of unknowns, attaching a small water processor that utilizes the envisioned technology on one of the rovers during an early flight will enable on-purpose measurement of water processing of the Martian water. To date, many rovers sent by government agencies have been sent with equipment specific for identifying trace elements to ensure their existence or to determine the material makeup of the various components. By sending a rover with a water processing plant, the ability to collect water, process it, and measure for trace contaminants dangerous to humans or plants would show significant value to the mission as well as general knowledge to academia and government agencies. The value to other entities may enable cost sharing while minimizing programmatic risks.

5.2.7 Establish CONOPS Early

As the ECLSS requirements will be driven by the crew activities, it is necessary to really understand not only the expected needs of the crew, but the time and space demands of the Mars One crew beyond life support. This is often stated as a servicing time limit requirement (measured in Person-Hours).

6 Habitat ECLSS Next Steps

A more in-depth round of conceptual design development should be completed with specific emphasis on addressing risks and opportunities identified in Section 5.1 (Identified Risks) and Section 5.2 (Opportunities to Reduce Risk).