Environmental Control and Life Support (ECLS) System Options for Mars Transit and Mars Surface Missions

Zach Bryant[1] and Andrew Choate[1]
Jacobs Space Exploration Group, NASA MSFC, Huntsville, AL, 35812

David Howard[2]
NASA MSFC, Huntsville, AL, 35812

The NASA led Artemis campaign will take humanity back to the Moon and serve as an analog for continued deep space exploration to Mars. Artemis utilizes crewed vehicles and habitats on both the Lunar surface and in Lunar orbit. The exploration of the Lunar surface and buildup of a basecamp is meant to be a "Mars forward" approach to testing and refining new technologies and techniques for living and working far outside of Low Earth Orbit (LEO) and preparing for future Mars missions. The Lunar Surface Habitat is planned as a primary element for long duration crew habitation on the Moon and will be the primary testbed for ECLS system hardware in a partial gravity environment. The Mars Transit Habitat will be the crew vehicle for the roundtrip from Earth to Mars and spend a significant amount of time docked to the Gateway outfitting and testing its systems prior to making the first Mars mission transit. The Mars Transit Habitat will utilize closed loop ECLS system technologies while a Mars Surface Habitat could use either open loop, closed loop, or a mix of both. Better understanding the needs of both these system architectures operating for extended periods in the Lunar environment and outside LEO will help to establish the ECLS system architecture for the future Mars surface mission. There are many aspects to consider such as length of crew stay, level of autonomy and dormancy between crewed missions, power requirements, system mass, and overall system reliability and maintainability. Other considerations will include Mars gravity vs. Lunar gravity, Mars atmospheric pressure vs. hard vacuum, and possible use of in-situ resource utilization.

Nomenclature

CDRA = Carbon Dioxide Removal Assembly
CH_4 = Methane
CO_2 = Carbon Dioxide
Cislunar = Space between Earth and the Moon
DST = Deep Space Transport
ECLS = Environmental Control and Life Support
EVA = Extravehicular Activity
FOD = Foreign Object Debris
g = Gravity of Earth
μg = Micro Gravity
H_2 = Hydrogen
LEO = Low Earth Orbit
LiOH = Lithium Hydroxide
ISS = International Space Station
ISRU = In-Situ Resource Utilization
M2M = Moon to Mars
MAV = Mars Ascent Vehicle
MDS = Mars Descent System
MPS = Mars Propulsion System
N_2 = Nitrogen
NASA = National Aeronautics and Space Administration
NRHO = Near-Rectilinear Halo Orbit
O_2 = Oxygen
OGA = Oxygen Generation Assembly
PR = Pressurized Rover
PSI = Pounds/Inch^2
PSIA = Pounds/Inch^2 Absolute
SH = Surface Habitat
Sol = One Martian day
SPE = Solar Particle Event
TH = Transit Habitat
UPA = Urine Processing Assembly
WPA = Water Process Assembly

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[1] Systems Engineer, Habitation Formulation Office, Mail Stop: HP40, MSFC, AL 35812
[2] Aerospace Engineer, ECLS Development Branch, Mail Stop: ES62, MSFC, AL 35812

I. Introduction

NASA is going back to the Moon and beyond to Mars. The successful launch and recovery of the Artemis-I mission in 2022 brings humanity closer to living and working in cislunar space for extended periods of time. Each step and mission of the Artemis campaign is meant to build upon the previous with the goal of creating a robust Lunar architecture that can be used as a Mars forward approach where technologies and techniques can be matured for the first human mission to Mars. This Mars mission will be longer than any other crewed mission before it and will require an ECLS system that has been proven through hardware development, ground testing, and in-flight testing within the International Space Station (ISS) program and on Artemis Lunar and Gateway missions. This paper will look at ECLS technologies and architectures currently being developed and refined that may be utilized during the Earth to Mars transit and the subsequent Mars surface missions. This may also shed light on the tipping point when best to utilize open loop vs closed loop ECLS architectures for crewed missions.

II. Overview of a Crewed Mars Mission

The current Moon to Mars (M2M) mission trade space includes a crew of four making up to a 1200 Earth-day roundtrip mission from earth orbit to Mars and back (Figure 1). This total transit duration includes a minimum 50 sol stay in Mars orbit which would support a minimum 30 sol two crew Mars surface mission.

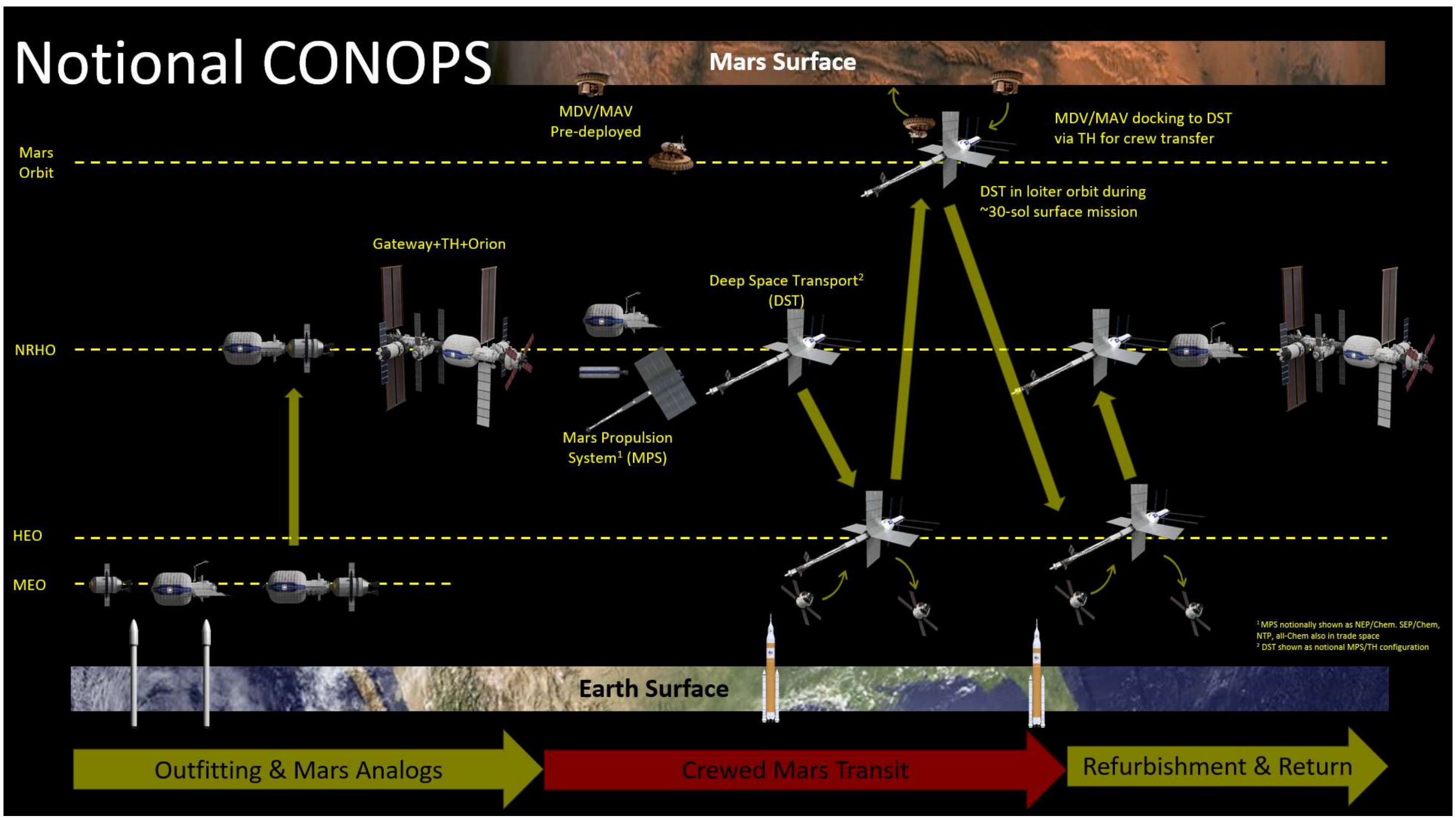

Figure 1. Human Mars Mission Layout

The Transit Habitat (TH) will function as the vehicle for housing crew during transit and orbital segments of the Mars mission. Prior to the start of the Mars mission, the TH will be docked with Gateway in a Lunar Near-Rectilinear Halo Orbit (NRHO). While docked at Gateway, the TH will be utilized to lengthen the allowable mission time of crew at Gateway and allow for the TH to be outfitted, systems verified, and the vehicle supplied for future missions. TH will also go through a series of shakedown testing and isolated crewed analog missions while docked at Gateway to better characterize its use and prepare for the first crewed Mars mission. Once testing is complete, the TH will be fully stocked with supplies through the use of logistics vehicles and be ready to depart Gateway, dock with the Mars Propulsion System (MPS) elements which will form the Deep Space Trasport (DST), pick up the crew and head for Mars. During the transit to Mars, crew will spend time performing tasks very similar to that of current ISS crews; maintaining system hardware, performing experiments and other utilization activities, exercising, conducting outreach events, and taking time off for relaxation and other recreation activities.

Once in Mars orbit, the TH will dock with the Mars Descent System (MDS) which will take a crew of two down to the Martian surface for a 30 sol mission. At the completion of the 30 sol mission, the crew will return to the TH in the Mars Ascent Vehicle (MAV), dock with the TH, and return to Earth.

Early Mars surface mission tasks may look very similar to the early Artemis Lunar surface missions with crew performing exploration activities (Extravehicular Activity (EVA), sample collection, science experiments, etc.) with the goal of maximizing time on the Martian surface.

This architecture poses several considerations for the TH and Mars surface habitation designs.

A. Resupply

There will be no on-demand crew resupply capability during the human Mars mission. All necessary supplies and consumables must be carried or pre-staged, as is the case for the Mars surface portion of the mission. As a point of reference, the ISS has been continuously crewed for over 20 years but receives regular cargo deliveries every few months with the longest time between resupply flights being a little over 100 days. The longest crewed mission on any space vehicle without cargo resupply was 182 days during the 2021/2022 Shenzhou 13 mission on the Chinese Tiangong station in LEO[1].

B. Abort

Mars transit abort options are minimal and do not offer quick return times to Earth on the order of hours or a few days as has been the case for all previous LEO and Lunar missions. Rather, the majority of abort options once leaving cislunar space result in return times of 300+ days[2]. Systems will need high reliability and redundancy (i.e., spares, backup systems) to allow for the crew's safe return to Earth orbit in the event of contingencies.

C. Mass

Logistics and cargo stowage is proportional to crew size and planned mission duration. The number of spares carried in the TH vehicle is largely driven by each system's assessed reliability. The more robust and reliable a system is, the less need to carry multiple spare parts. The overall vehicle mass will drive mission propulsion needs which in turn will play into which orbital trajectories are used and thus how long the mission will be.

D. Communication

Large portions of the mission will have significant communication delays between the crew/vehicle and the mission control teams on Earth. There is the possibility for total communication blackout periods for multiple days depending on the final orbital trajectory chosen[3]. This is in contrast to ISS operations and cislunar space that offer near real time constant communication with mission control. In general, for ISS operations, teams of engineers on the ground provide support through problem solving, procedure development, and real time implementation support to assist crew in resolving system errors and repairs. The lack of real-time communication on Mars missions will drive the crew to be more self-sufficient when it comes to system repairs. Systems will need to have a level of repairability and maintainability that does not require extensive ground interaction. Additionally, systems should consider using automation to reduce regular maintenance time and attention required by crew.

III. Mars Transit Habitat

The TH will transport four crew from Earth orbit to Mars and back while also carrying all the necessary systems, hardware, and supplies for the round trip. The government reference design for the TH vehicle is currently under development by the NASA Habitation Systems Development Office. This reference design is a concept for supporting analyses and potential mission designs but does not necessarily represent the final vehicle that will ultimately perform the missions. The reference design is currently a hybrid architecture utilizing both metallic and inflatable sections to maximize available size while reducing overall mass[4]. The TH will provide a safe and productive living and working environment for the crew similar to the ISS. Crew will be able to perform scientific experiments and other utilization operations onboard TH and thus may require some support from the ECLS systems (e.g., gas supply, vacuum exhaust, ventilation, etc.) beyond nominal life support. In the case of an emergency (i.e., fire, cabin depress, etc.), TH will provide a safe haven where crew can shelter for a short period of time (i.e., up to a few days)[5]. This safe haven will provide ECLS for the shelter duration until the issue can be resolved. TH will be able to utilize the metallic section as an airlock and support EVAs on a contingency basis during transit. This drives the need for airlock functions and accompanying systems (i.e., EVA capable hatch, isolated depress/repress capability, suit interface, etc.). TH will be required to dock to a variety of different vehicles (i.e., Gateway, Orion, MDS, etc.) with varying atmospheric pressure requirements and must be able to operate at a varying array of internal pressures from a low of 10.2 psia to a nominal 14.7 psia and subsequently oxygen (O_2) concentrations between 27% to 20%.

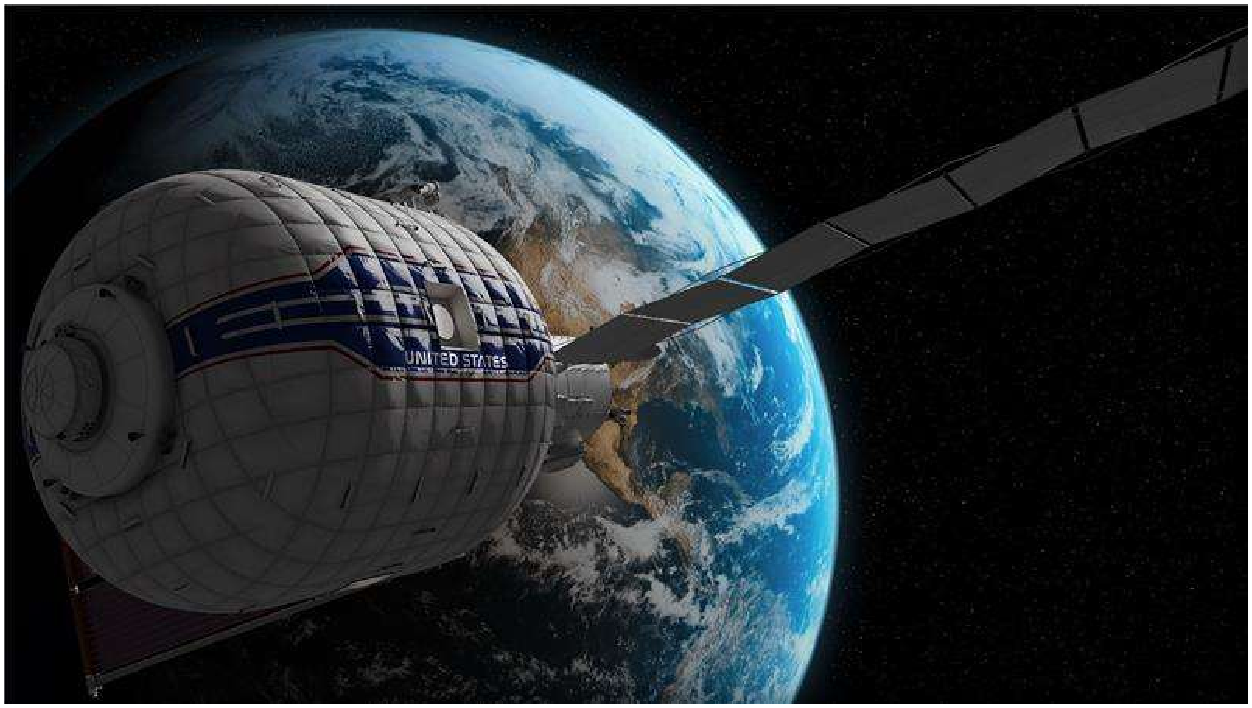

Figure 2. Transit Hab Government Reference Concept Design

During the Mars mission, TH will be continually crewed. Prior to that, there will be periods of up to 3 years in NRHO when TH will be uncrewed and systems will be in a dormant state. ECLS subsystems will need to be designed with these dormancy periods in mind such that a stable environment can be maintained while also allowing for an efficient return to full service upon crew arrival. During this time prior to the Mars mission, TH will be docked to Gateway. This will enable Gateway to perform long duration crewed Mars analog missions. While TH operates nominally at 14.7 psia, it will accommodate Gateway's 10.2 psia environment while docked and hatch open. When crew is not present, TH will isolate from Gateway. These analog missions will include isolating TH from the rest of Gateway and allowing crew to test out the TH as a standalone vehicle.

The lack of resupply during the Mars mission increases the need for the overall ECLS systems to have a higher level of reliability than current ISS technology. The lack of resupply also eliminates the ability to resupply ECLS system consumables and is a major driver of the overall TH ECLS system architecture. The extended communication delay will also make system repair and ease of maintainability a high priority since ground teams will not be able to provide near real-time support, as has been the case on ISS.

The factors above (i.e., length of the mission, mass constraints, lack of resupply) make using a regenerative ECLS system a must. As part of the overall M2M campaign, the ECLS focus will be on utilizing mechanical and chemical processes. Biological based ECLS systems are not being considered at this time[6]. The following subsections will outline the currently proposed TH ECLS system and why this architecture is favored.

A. TH Regenerative ECLS

TH will require the use of regenerative (regen) ECLS systems that will allow for a closed loop architecture. This will eliminate the need for resupply and allow for the vehicle to be self-sufficient.

1. Oxygen Generation

Oxygen generation is a key driving factor for implementing a regenerative ECLS system. Providing tanked O_2 for the entire length of the mission would be prohibitive due to the mass and volume required. A system similar to the ISS Oxygen Generation Assembly (OGA) would allow for O_2 generation through water electrolysis. This would suffice for nominal cabin pressure ranges (10.2 psia to 14.7 psia) but would also need to be able to provide O_2 at a much higher pressure (>3,000 psia) for EVA suit recharge. This higher pressure O_2 could be stepped up through pumps and/or a combination of new OGA system. This high pressure O_2 would need to be stored for use as needed by the EVA system.

2. Carbon Dioxide Removal

Carbon dioxide (CO_2) removal will keep the atmosphere breathable and will also be a step in the necessary water recovery loop. Open loop methods of carbon dioxide removal such as lithium hydroxide (LiOH) or absorption/desorption overboard would require too many consumables (i.e., LiOH cartridges, O_2 loss) and would not provide a means to reuse CO_2 for use in water recovery. A carbon dioxide removal system, such as one similar to the legacy Carbon Dioxide Removal Assembly (CDRA) or newer Four Bed CO_2 scrubber[7] on ISS, will need to scrub CO_2 from the cabin atmosphere and provide it to downstream systems for further processing.

3. Water Recovery

TH has multiple means for water recovery, similar to current ISS operations. One of these will be to recover crew urine. TH will collect and process crew urine through a system such as the Urine Processing Assembly (UPA) being used on the ISS. This method utilizes vapor compression distillation to recover a high amount of water from the urine but also leaves behind a brine slurry allowing for further processing potential. A brine processor would work in conjunction with the UPA to process the leftover brine and provide additional water to the recovery loop. Another means of recovery is that of atmospheric moisture from crew sweat, respiration, and general water evaporation. TH atmospheric moisture will be collected via condensation and stored for further processing.

The final step of water recovery is to process the collected water to a potable state that can be used for all the various functions of the TH. A system similar to the ISS Water Process Assembly (WPA) will process the water recovered from the Sabatier and plasma pyrolysis process, UPA and brine processor, and from cabin condensate. It will need to remove any chemicals and microbes in the water so that it will be safe for crew consumption and vehicle system use (i.e., OGA, EVA, experiments, etc.)

One nuance to consider with the water recovery is that of water from food. As crew consumes prestored food, that water content in the food (currently planned at 30% for stowed food) will make its way back into the vehicle water recovery system via crew urine and sweat. As a result, there is a potential to have an excess of water onboard. To preclude the need to vent the water to space, the system should be balanced as best possible to level out the necessary water recovery.

4. Water Generation

A system using the Sabatier process (or other recovery process) will utilize the captured CO_2 in conjunction with waste hydrogen (H_2) from the OGA to create water. This water production will close the ECLS loop and allow for all necessary mission water to be created/recycled onboard. There is opportunity to provide further efficiency to this closed loop water process using additional processes such as plasma pyrolysis that will take the waste gas methane (CH_4) from the Sabatier process to further recover water. The waste gasses from this process (acetylene) would then be vented to space.

B. TH Non-Regen ECLS

TH will require additional ECLS systems beyond the core regen functions. These non-regen systems are necessary to maintain a habitable vehicle and will work in conjunction with the regen side of the ECLS system.

1. Atmosphere Control

Atmospheric control will be needed in conjunction with O_2 generation and CO_2 removal. This will allow for TH to monitor and control overall habitat pressure and individual atmospheric partial pressures. A tanked supply of gas (both O_2 and nitrogen (N_2)) will be needed for the initial vehicle inflation and to make up for nominal atmospheric leakage and losses due to dockings, trash jettison, and EVAs. Tanked gas can also be used for experiments and other utilization tasks while also acting as a storage tank for high pressure O_2 generation for EVA purposes. There will also be a need for vents to space, to allow systems to vent gas if/when needed and provide for venting residual atmosphere in the case of dockings, EVAs, or any experiments that may require the use of hard vacuum.

The atmospheric control system will monitor and regulate the atmospheric pressure throughout TH. It should be noted that TH and all the various systems, including ECLS, will need to operate down to 10.2 psia (and perhaps even lower) depending on the phase of the mission and which visiting vehicles it is docked with. This is expected to drive efficiency changes throughout the ECLS system as the atmospheric density drops.

2. Temperature and Humidity Control

The temperature and humidity control system will need to provide ventilation for crew comfort and homogenous gas mixing. This ventilation will need to keep the air moving throughout TH to ensure even mixing of the atmosphere. This system will also need to have the ability to filter and scrub the air to remove dust, debris, and other trace contaminants. The system will need to provide cool conditioned air to the crew and control the humidity levels in the cabin. The use of a condensing heat exchanger that can recover atmospheric moisture and deliver it to the water recovery system will be vital to the overall loop closure of the regen water recovery system.

3. Emergency Equipment

The final pieces of the ECLS system are to account for emergency situations such as a fire. Crew will need a means to breathe in the event of smoke and other possible atmospheric contaminations. Additionally, there should be a system to extinguish a fire through crew handled devices and/or a vehicle-level fire suppression system.

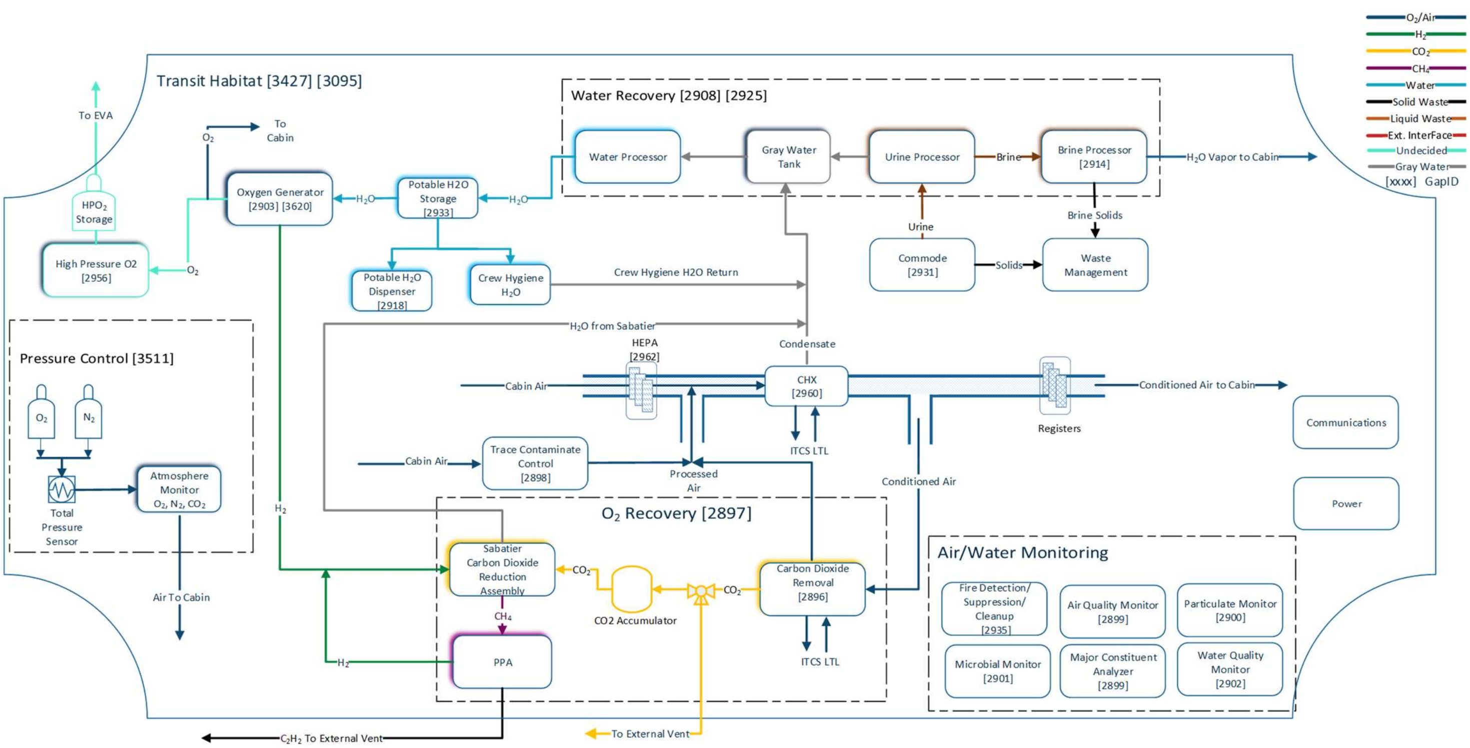

Figure 3. Notional TH ECLS System Block Diagram

IV. Mars Surface Habitats

The NASA Government Reference Mars surface habitat concept is not as well defined as the TH vehicle, although these habitats will build off the work and lessons learned by the Lunar Surface Habitat (SH) element. The primary goals of the first Mars mission will be to put boots on the surface, gather samples, and safely return the crew. At a minimum, two crew would descend to the Martian surface and stay in a pressurized rover (PR) similar to the plan for Lunar surface missions[8]. For limited crew, short surface stays, a fixed habitat may not be necessary, but subsequent Mars missions may utilize larger/multiple habitats to establish a larger presence and enable longer surface stays similar to the current Lunar surface mission outline.

Lunar surface missions are being used to help mature and develop systems for the Martian surface, but there are key differences between the two. Martian gravity is higher (3/8g on Mars vs. 1/6g on the Moon). There is an atmosphere on Mars (i.e., some atmospheric pressure, gaseous elements, and weather patterns), whereas the Moon is a hard vacuum. Martian dust is quite different from Lunar regolith (i.e., not electrostatically charged, less abrasive, has perchlorate content). Temperature differences and lighting condition could also factor into system considerations. Finally, the available resources on the two planetary bodies are different in both distribution and content. Another important factor is that of planetary protection. The desire is to significantly minimize biological contamination of the Martian surface, thus all waste and system byproducts (i.e., trash, fluids, vented gasses, spills) that will come in contact with the Martian environment will need to be managed thoughtfully[9].

In-situ Resource Utilization (ISRU), which utilizes local resources as materials to complete mission objectives, may not be available for initial Mars surface missions. Biological (or bioregenerative) technologies are also not being considered for initial Mars surface missions[6]. These approaches, however, could be pursued in future architecture iterations.

The above key differences, along with the overall surface mission architecture will drive the Mars habitat ECLS systems to look different from the Lunar surface systems. The following subsections will outline possible Mars surface habitat ECLS system options and why these architectures have been chosen.

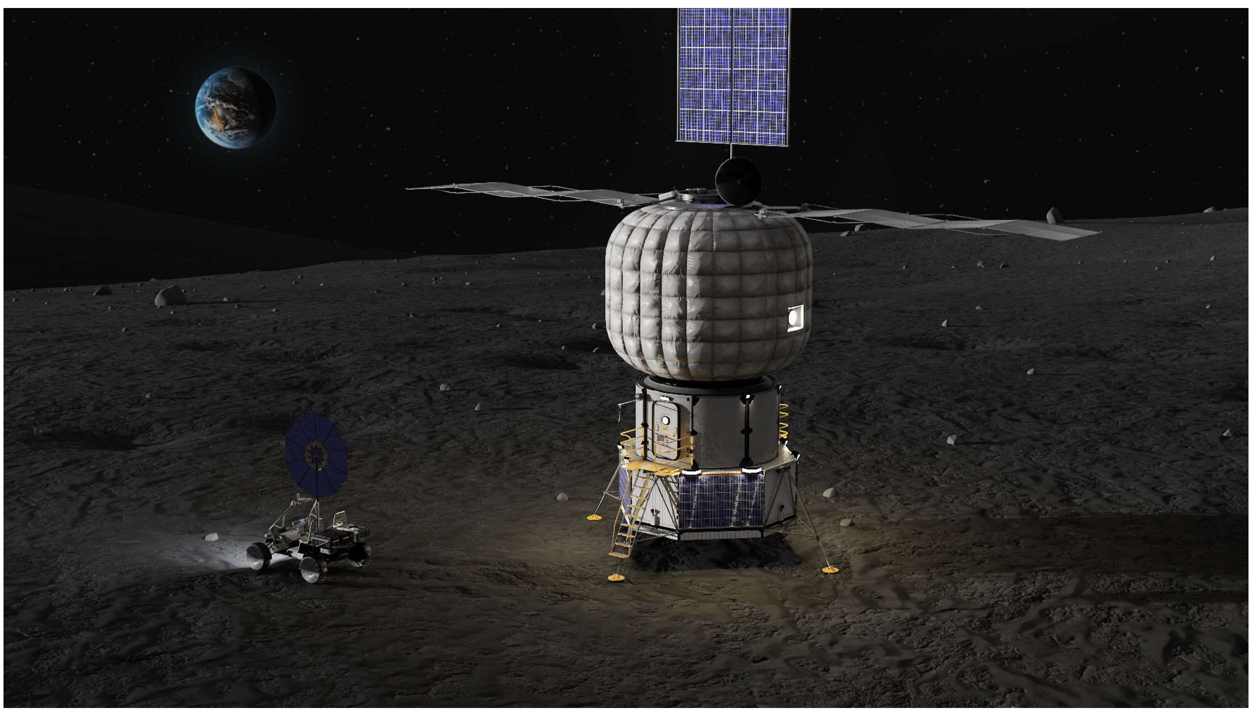

Figure 4. Lunar Surface Habitat, Pressurized Rover, and Lunar Terrain Vehicle Concepts

A. Initial Mars Surface Missions

At a minimum, a crew of two will utilize a PR-type habitat for the duration of their stay. The PR must sustain the crew for 30 sols and will be their only means of habitation. It will be small in size, power limited, and offer little in the way of space and privacy. All necessary ECLS systems will be integrated into the PR. Due to these factors it is assumed that the ECLS system will be of an open loop architecture. All necessary consumables will be onboard the MDS and ready for offload to the PR at the start of the surface stay. The PR will return to the MDS to restock supplies at pre-defined times throughout the surface stay[10]. Planetary protection considerations, such as microbial vent filters, may be required on PR ECLS systems.

1. Tanked metabolic gas and makeup gas

The atmospheric pressure and metabolic O_2 will be maintained by tanked high pressure gas. This will most likely also be used to recharge the EVA suits and thus may require multiple tanks to maintain a high pressure (3000 psia). There will also need to be a sufficient supply of gaseous N_2 to provide atmospheric makeup due to losses from leakage and EVAs.

2. Tanked water

All necessary water will be provided as a consumable and thus will not be recycled or regenerated. There will need to be sufficient water provided for crew hygiene, drink and food prep, possibly for the toilet system, and to recharge the EVA suits. Used water will most likely be stored rather than dumped overboard. To preclude microbial growth in the water there will need to be a biocide added such as Iodine or Silver[11]. This biocide should be able to be filtered out of the water or be compatible with the EVA suits, wetted systems, and safe for crew consumtion.

3. Storage of urine

Since this will be an open loop system the crew urine will not be recycled for reuse. Thus, it must be stored in a safe manner that does not present a hazard to the crew or a discomfort in the way of smell. Some consideration should be given to the reuse of this stored urine. Although unlikely to occur in early missions, it could possibly be offloaded and recycled in future missions if the available regen infrastructure is present. Stored urine will also need to comply with planetary protection requirements which may necessitate sterilization or robust long term stowage designs.

4. Small CO_2 scrubber

Although consumable LiOH could be used to scrub CO_2, it would most likely take up too much valuable cabin volume. A small CO_2 scrubber, such as an amine type system, could work in this setting and would preclude the need for consumable cartridges.

5. Filtration and ventilation

Filtration will be especially vital on the surface of Mars. Although there will be plans to minimize dust intrusion into the cabin, it will inevitably find its way inside the habitable volume. The filtration system will need to efficiently remove the dust from the cabin atmosphere to minimize interference with system operations. Martian dust is known to contain toxic perchlorates that can affect crew health and needs to be quickly removed within the PR's habitable cabin environment. Although the PR's cabin will be small and there will be partial gravity, ventilation will be needed to move the air around and provide a comfortable living environment for the crew.

6. Humidity removal

Since there will be no need to recover water in the PR, a condensing heat exchanger is not necessary, although it is an option to collect the condensate and on future missions could be offloaded to a regen system for recycling. Other options could include using a membrane type system to remove and control humidity. A rapid cycle amine[12] system could also be used with the added benefit of controlling humidity and removing CO_2. This would eliminate the need for additional storage tanks while also reducing power requirements.

Figure 5. Notional Mars Descent System and Pressurized Rover

B. Subsequent and Sustained Mars Missions

Looking beyond the initial Mars surface mission(s) to a sustained presence enables additional ECLS system options and capabilities. The assumption is that future missions will take the same approach as the Lunar surface allowing for larger crew sizes and longer duration stays (i.e., beyond 30 sols). These missions could utilize larger/multiple habitats similar to the Lunar Surface Habitat concept[13]. A larger habitat size will allow for more volume, stowage, and power.

1. Regen ECLS

Longer surface missions and larger crew sizes will drive the need to go beyond an open loop consumable based ECLS system. A regen type system will be needed to produce O_2 and recycle water similar to the systems being utilized on the TH (O_2 generation, CO_2 removal/recovery, Sabatier/plasma pyrolysis, UPA/brine processor, WPA). The regen systems could also be used to process stored urine and wastewater offloaded from the PR minimizing its need to use open loop consumables.

Regen systems residing on the Martian surface will be subjected to 3/8g loading. Traditional regen systems have been proven through extensive testing on Earth in 1g and for many years on ISS in μg. Regen systems are planned to eventually be utilized as part of the Lunar Surface Habitat architecture which will allow for testing and hardware maturation in a partial gravity environment (1/6g on the Moon). Some issues that could affect these regen systems include particulate separation, precipitation of solids, growth of biomass, and entrainment of regolith-based dust with condensate separation systems.

Managing dust will be an important part of the ECLS system. Martian regolith does not present the same challenges as Lunar regolith in relation to electrostatic properties and abrasiveness, but it does bring about a new challenge in the form of toxicity (perchlorates). The ECLS system will need to be able to filter out the dust and minimize crew exposure to toxic chemicals. The filtration will also need to protect the condensing heat exchanger from fouling due to regolith if condensate recovery is part of the architecture.

As with the TH, there will be a need to recharge EVA portable life support systems >3000 psi. This will require the ability to produce high pressure O_2 that can be stored for future use. All other systems would be similar to the TH (i.e., pressure monitoring, vents/vacuum availability, and emergency hardware). Although there is a slight atmosphere on Mars, the pressure (~5 torr) is still low enough that venting waste gasses overboard or utilizing the outside environment as a vacuum resource should not be a great concern but could add operational inefficiencies (i.e., longer vent times and slower bake outs).

2. ISRU ECLS

Another option for long duration ECLS that can work in conjunction with regen systems or by itself in an open loop configuration is that of ISRU. ISRU will allow for using local resources to reduce the need to bring all necessary supplies along. This could include transforming resources into breathable air and water. Although there are currently no plans in the M2M architecture for ISRU on the Mars surface, there are plans to test these technologies and techniques on the Moon as a means to evaluate the benefit of locally produced resources against the operational complexity of extraction and processing. Although both the Moon and Mars have useable local resources, they have key differences. The Moon and Mars both have water in the form of ice, although the state of each ice deposit and methods of possible extraction varies. Recovery and processing methods that work on the Moon are not likely to completely translate to recovery of Martian ice deposits. Once the ice is recovered, it can be processed into liquid water and fed into a regen system for use as O_2 through electrolysis or pre-processed through the water processing system for general use. This water could also just feed an open loop ECLS system and act as a consumable.

The other main resource is O_2. While there is a possibility to extract O_2 from Lunar and Martian regolith using varying methods, the high concentration of CO_2 (95%) in the Martian atmosphere may offer the easier route. NASA flew the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) on the Mars Perseverance rover currently operating on the Martian surface. This hardware experiment was able to produce O_2 from atmospheric CO_2 using solid oxide electrolysis[14]. This O_2 production, much like the water production, could be utilized as part of a regen system or used as a consumable.

3. Dormancy

For both these long duration options dormancy periods will come into play. There is currently no set time for mission cadence, but optimal Mars departure opportunities occur every ~2 years. All systems will need to be designed with dormancy in mind with the goal to reduce crew time needed to put systems in a dormant state and bring them back online at a later date. Water systems will be impacted the most by dormancy and may require a significant amount of time to prepare for the dormant state. Wetted systems will need to be designed to allow for ease of flushing lines/hardware, minimizing dead legs, and optimizing tubing designs among other considerations[15].

V. Conclusion

Planning for the first human Mars mission is underway, driving the need for enhanced and possibly alternative ECLS system architectures than are currently in use on ISS. A human Mars exploration campaign brings about many challenges to the ECLS system such as lack of resupply, reliability and maintainability, extended dormancy periods, dust, and eventually ISRU integration.

The current TH architecture will utilize many legacy ISS type systems that will be upgraded to a next generation level and allow for a high level of loop closure for the long duration mission. Mars surface habitation will build off of Lunar habitat design utilizing both open loop, for the initial short-term stays, and closed loop designs, for subsequent longer duration stays, with a possible long-term transition towards ISRU. Although final architectures are far from finalized the goal of this paper is to offer some possible paths forward and allow for the greater ECLS community to keep a Mars forward approach.

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References

[1]Owens, A. C., Cirillo, W. M., Stromgren, C., Cho, J., Lynch, C., and Vega, J. M., "Integrated Logistics and Supportability Challenges of Sustained Human Lunar Exploration," 51st International Conference on Environmental Systems, St. Paul, MN, July 10-14, 2022, ICES-2022-90.

[2]Chai, P. R., Qu, M., "Human Mars Mission Transit Abort Options for Ballistic High Thrust and Hybrid Transportation Systems," ASCEND 2022, Las Vegas, NV, October 24-26, 2022, 10.2514/6.2022-4374.

[3]"Reference Surface Activities For Crewed Mars Mission Systems and Utilization," Publication HEOMD-415 Version 1, National Aeronautics and Space Administration, January 24, 2022.

[4]Choate, A., Kessler, P., Nickens, T., et al., "NASA's Moon to Mars (M2M) Transit Habitat Refinement Point of Departure Design," IEEE Aerospace, March 2023.

[5]Harris, D. W., Kessler, P. D., Nickens, T. M., Choate, A. J., Horvath, B. L., Simon, M. A., Stromgren, C., "Moon to Mars (M2M) Habitation Considerations, A snap Shot As of January 2022," Publication TM-20220000524, National Aeronautics and Space Administration, January, 2022.

[6]"Exploration Systems Development Mission Directorate, Moon To Mars Architecture Definition Document, Volume – 1 Overview And Strategy," Publication ESDMD-001. National Aeronautics and Space Administration, (to be published).

[7]Cmarik, G., Peters, W., Knox, J., "4-Bed CO2 Scrubber – From Design to Build," 50th International Conference on Environmental Systems, Lisbon, Portugal, July 12-16, 2020, ICES-2020-178.

[8]Rucker, M., Craig, D., Burke, L., et al., "NASA's Strategic Analysis Cycle 2021 (SAC21) Human Mars Architecture," IEEE Aerospace, March 6-13, 2021.

[9]Conley, C. A., Rummel, J. D., "Planetary protection for human exploration of Mars," Acta Astronautica, 66 (2010), 792-797.

[10]"Reference Surface Activities For Crewed Mars Mission Systems And Utilization,", Publication HEOMD-415 Version 1, National Aeronautics and Space Administration, January 24, 2022.

[11]Li, W., Calle, L. M., Hanford, A. J., Stambaugh, I., Callahan, M. R., "Investigation of Silver Biocide as a Disinfection Technology for Spacecraft – An Early Literature Review," 48th International Conference on Environmental Systems, Albuquerque, NM, July 8-12, 2018, ICES-2018-82.

[12]Chullen, C., Campbell, C., Papale, W., Hawes, K., Wichowski, R., "Rapid Cycle Amine 3.0 System Development," 45th International Conference on Environmental Systems, Bellevue, WA, July 12-16, 2015, ICES-2015-313.

[13]Kessler, P., Prater, T., Nickens, T., Harris, D., "Artemis Deep Space Habitation: Enabling a Sustained Human Presence on the Moon and Beyond," IEEE Aerospace, March 5-12, 2022.

[14]Hoffman, J. A., Hecht, M. H., Rapp, D., et al., "Mars Oxygen ISRU Experiment (MOXIE)-Preparing for human Mars exploration," Sci Adv, 2022, 8(35):eabp8636.

[15]Carter, D. L., "Dormancy Assessment for Advanced Exploration Systems (AES)," NASA MSFC, Hunstville, AL, July, 2018.