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NASA Extravehicular Activity Technology Roadmaps for Exploration

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The National Aeronautics and Space Administration (NASA) has developed and matured many technologies over the decades to advance extravehicular activity (EVA) systems. Over the last 15 years, major steps were taken to advance the technology with the Exploration Extravehicular Mobility Unit (xEMU) government reference design at the Johnson Space Center (JSC) in Houston, Texas. The xEMU builds on the lessons learned of the Apollo, Space Shuttle, and International Space Station (ISS) EMUs, evolving the technology to increase performance for extreme environments. As NASA sets its goals toward Earth's Moon and Mars, a spacesuit design tolerable of gravity and dust will be needed for these adverse environments. NASA has used roadmaps as the means of documenting actionable plans for strategizing technology developments needed to meet NASA's mission and goals. To help reach and create a sustained presence on the Moon, NASA procured EVA services from industry through the Exploration EVA Services (xEVAS) contract. These services include certified contractor-provided spacesuits, tools, equipment, vehicle interfaces, and support to training and real-time operations. NASA will now focus on a mission to Mars. NASA leadership has set goals and objectives related to the Agency's vision and a Moon to Mars (M2M) strategy. This paper presents an organizational framework to provide insight into how NASA's vision is realized. Additionally, this paper covers the maturation and development of the spacesuit technology and reveals the EVA technology roadmaps for the M2M Program. These EVA roadmaps visualize an actionable path to EVA capabilities needed for Mars exploration.

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Nomenclature

ADD	=	Architecture Definition Document
CHP	=	Crew Health and Performance
CM	=	crew member
CTSD	=	Crew and Thermal Systems Division
EA	=	Engineering Directorate
EC	=	Crew and Thermal Systems Division
EC5	=	Space Suit and Crew Survival Systems Branch
ECLSS	=	Environmental Control and Life Support Systems
EHP	=	Extravehicular Activity and Human Surface Mobility Program
EIO	=	Earth Independent Operations
EMU	=	Extravehicular Mobility Unit
EPG	=	environmental protection garment
ESDMD	=	Exploration Systems Development Mission Directorate
EVA	=	extravehicular activity
FY	=	Fiscal Year
GFE	=	government-furnished equipment
HLS	=	Human Landing System
ISS	=	International Space Station
IVA	=	intravehicular activity
JSC	=	Johnson Space Center
LEO	=	Low Earth Orbit
LTV	=	lunar terrain vehicle
MCO	=	Mars Campaign Office
M2M	=	Moon to Mars
O_2	=	oxygen
PGS	=	Pressure Garment System
PLSS	=	Portable Life Support System
PR	=	pressurized rover
RFI	=	Request for Information
RFP	=	Request for Proposal
SAO	=	Strategy and Architecture Office
SBIR	=	Small Business Innovative Research
SCLT	=	Strategic Capabilities and Leadership Teams
STIP	=	Strategic Space Technology Investment Plan
STMD	=	Space Technology Mission Directorate
STTR	=	Small Business Technology Transfer
TI&P	=	Technology Integration & Partnerships
TRL	=	Technology Readiness Level
xEMU	=	Exploration Extravehicular Mobility Unit
xEVAS	=	Exploration Extravehicular Activity Services contract
xPGS	=	Exploration Pressure Garment System

I. Introduction

PERFORMING an Extravehicular Activity (EVA) is one of the most critical operations of human space flight because of the hazardous space environment, which is unique, extreme, and harsh. A crew member (CM) wearing an EVA spacesuit would be exposed to the various atmospheric conditions, temperature extremes, radiation, and contend with different environments of the Moon and Mars.[1] An EVA spacesuit provides a life sustaining and safe environment for a CM outside the primary vehicle. The spacesuit NASA has used for EVAs is known as the Extravehicular Mobility Unit (EMU). CMs in their EMUs have walked on the surface of the Moon during the Apollo Program, inspected and repaired the Hubble Space Telescope during the Space Shuttle Program, and built (and maintained for more than 20 years) the International Space Station (ISS), along with many other critical jobs. There have been many technological achievements and advancements in the EVA spacesuit to meet programmatic objectives. Future EVA spacesuits, whether designed for orbital operations or planetary surface explorations systems, must continue to be safe and reliable and must provide a high degree of performance capabilities.[2]

As NASA sets its goals toward the Moon and Mars, a spacesuit design tolerable of gravity and dust will be needed for these adverse environments. The Exploration EMU (xEMU) government reference design was built based on over 15 years of evolutionary technological progress and lessons learned and can serve as a foundation of knowledge for future spacesuits.[3] NASA has awarded two vendors through the Exploration Extravehicular Activity Services (xEVAS) contract to be commercial suppliers for the EVA spacesuits for ISS and for the Moon.[4] NASA will now focus on Moon to Mars (M2M). NASA leadership has set goals and objectives related to the Agency's vision and M2M strategy.[5] NASA has created the M2M Architecture Definition Document (ADD). The ADD captures the methodology and organization necessary to translate the broad objectives outlined in the M2M strategy into functions and use cases that can be allocated to implementable programs and projects. One of the characteristics and needs in the ADD is to provide capabilities to conduct EVA activities.[6]

NASA has used roadmaps as the means of documenting actionable plans for strategizing technology developments needed to meet NASA's mission and goals. In 2012, NASA published 14 Space Technology Roadmaps. These roadmaps were published in a set of Agency-wide documents that included needed technologies with a focus on applied research and development. Additionally, NASA created a NASA Strategic Space Technology Investment Plan (STIP) after NASA developed these roadmaps. The STIP served to identify a strategy for prioritizing and investing into the roadmap technologies. As revealed in the STIP, NASA planned to implement an Agency-wide, web-based software system known as NASA TechPort. Although the developed roadmaps are no longer in effect, the NASA TechPort website remains active today and serves to integrate and disseminate key information about NASA investments in space technology.[7,8] NASA TechPort continues to provide information on technology programs and projects.

One of the 2012 roadmaps, titled "Human Health, Life Support and Habitation Systems Technology Area 06," summarized the key capabilities, including game-changing or breakthrough items, within the domain of TA06, necessary to achieve predicted national and Agency goals in space over the next few decades.[9] In particular, this roadmap states that "EVA systems are critical to every foreseeable human exploration mission for in-space microgravity EVA and for planetary surface exploration." For EVA, this document identified the technical need for a spacesuit, the current state-of-art technologies, the major challenges, and recommended milestones and activities necessary to advance to Technology Readiness Level (TRL)-6 or beyond. Although this roadmap is no longer active, it laid the foundation for development of the xEMU government reference spacesuit and the EVA roadmaps for M2M.

This paper covers the maturation and development of the spacesuit technology, provides an organizational framework to provide insight into how NASA's vision is realized, and reveals the new EVA technology roadmaps for the M2M Program. The EVA roadmaps within this paper visualize an actionable plan to realize EVA capabilities needed for Mars exploration. Roadmaps facilitate coordination within NASA for discussion, decision making, and planning for programs and development projects. They are not expected to accurately depict the details and statuses of the projects and tasks appearing within the plans. Roadmaps also communicate technological needs to industry, academia, and the public.

II. Organizational Framework

EVAs will continue to be required for future missions, including returning to the surface of the Moon and exploring Mars. Spacesuits will be a critical component of those missions. Since the development of the EMU used for Apollo, a slow progression of EVA technology development was made possible by such programs as the Space Shuttle, the ISS, the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR), and university grants. Over the last 16 years, NASA has been pursuing the next generation spacesuit known as the xEMU government reference design. Many programs and mission directorates facilitated the advanced development of the xEMU. As NASA facilitates the commercially developed spacesuits for ISS and lunar surface missions, the xEMU government reference suit will be used as a verification and test unit. However, as NASA pursues future missions to Mars, advancing the technology even further to meet mission requirements will be required. Advanced development in EVA capability for future missions to Mars cannot occur without vision and programmatic support. These elements exist in the organization framework depicted in Figure 1, which communicates the relationship in the Exploration Systems Development Mission Directorate (ESDMD) of the Strategy and Architecture Office, the M2M Program Office, Extravehicular Activity and Human Surface Mobility Program (EHP), and the Johnson Space Center (JSC) Engineering Directorate (EA). The Strategy and Architecture Office (SAO) owns and annually updates the ESDMD M2M ADD.[6] The M2M ADD establishes the processes, framework, and objectives for human exploration missions.

It serves as the guiding document from which EVA system capabilities needed for M2M foundational exploration and beyond were formulated. The implementing organizations within the M2M Program Office, EHP, and JSC EA are described in Sections II and III, respectively. In Figure 1, the Mars Campaign Office (MCO) within the M2M Program Office is the primary funding source for the EVA roadmaps. The funding path flows from the MCO to the EHP. EHP within the M2M Program Office is responsible for EVA enabling the M2M architecture. The funding further flows from EHP through the EHP Technology Integration & Partnerships (TI&P) Office to EA. TI&P is responsible for technology integration efforts to reduce project risks and for maturing key technologies required to enable the lunar architecture. The Space Suit and Crew Survival Systems Branch (EC5) is the supplying organization to EHP TI&P where the execution of the technology advancement occurs.

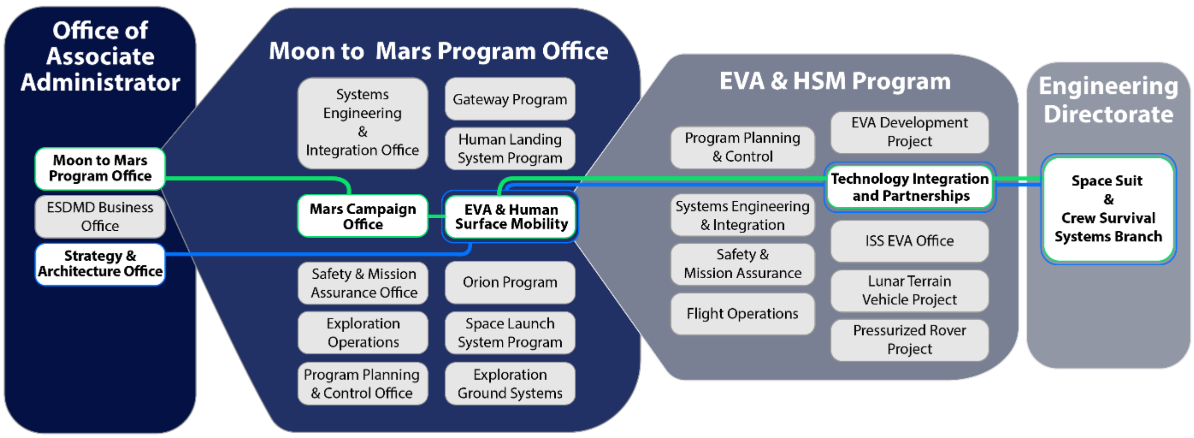


Figure 1. ESDMD Funding/Guidance Path

A. Mars Campaign Office

The MCO matures exploration capabilities and transit solutions to enable future missions to Mars through development activities on Earth, in low Earth orbit (LEO), in lunar orbit, and on the lunar surface, with an emphasis on filling high priority technology gaps identified by the Agency Strategic Capabilities and Leadership Teams (SCLT), Agency Principal Technologists, and the M2M Programs. The performance and reliability of prototype systems are demonstrated in ISS flight experiments and integrated ground tests. The MCO is strategically realigning itself in fiscal year (FY) 2024 to be more reflective of Artemis mission needs, goals, and objectives, consistent with requirements identified by the M2M programs and the ESDMD SAO. The MCO has been restructured into six domains: 1) Environmental Control and Life Support Systems (ECLSS), 2) Crew Health and Performance (CHP), 3) Earth Independent Operations (EIO), 4) Transportation and Vehicle Systems, 5) Surface Systems and Environments, and 6) Science and Infrastructure. The domains are further divided into activity areas that focus a small portfolio of tasks around a central theme. Domain-specific priorities for each activity area are identified by the domain leads based upon prioritized development plans for the maturation of systems to enable long-duration lunar surface and Mars transit missions. During the annual budget cycle, activity area leads develop requirements-based proposals in response to the domain priorities. New start activities are also considered at the start of the budget cycle, provided that the new proposal has advocacy from the appropriate MCO domain lead, identifies a feasible infusion path, addresses a gap and/or roadmap closure path with specific performance parameters of interest, and identifies an advocate from at least one of the M2M programs to support eventual flight program infusion.

B. Extravehicular Activity and Human Surface Mobility Program Technology Integration & Partnerships Office

EHP is one of the six programs comprising the M2M Program. Figure 2 shows the EHP patch. EHP is responsible for EVAs, rovers, and lunar surface integration to enable the M2M architecture. The EHP TI&P office is responsible for overseeing EHP technology integration efforts to reduce project risks and mature key technologies required to enable the lunar architecture. TI&P collaborates across the agency's mission directorates providing programmatic and technical inputs to their activities. Collaboration with the Space Technology Mission Directorate (STMD)'s SBIR and STTR Programs enables EHP to champion maturation of low TRLs technologies that align with program needs. This collaboration aligns well with the strategy visualized in the EVA roadmaps discussed in Section IV. As with other disciplines and systems, Agency-wide investment is needed to mature the capabilities necessary for human exploration beyond LEO. EHP's partnerships with industry serve as another means of collaboration for technology maturation and integration. The EHP Partnering Opportunity letter[10] seeks collaborations to advance technologies associated with human surface mobility in support of NASA's Artemis missions.

Figure 2. EHP Patch

TI&P has developed a strategy intended to target infusion into EHP flight projects to inform investment selection. The approach focuses on "pulling up" technologies that are being developed by STMD[11] and industry. Each activity on the roadmap represents a capability that the program needs. As the technology options for a given capability are developed and evaluated, a down-select decision is made in partnership with the project office and vendors. TI&P annually updates a priority list of EHP capability gaps that are used to develop and maintain the EHP technology roadmaps. These two products distill updates across the ESDMD enterprise, including the annual SAO-led ADD publication and the progress of the EVA development teams to identify a tactical plan to achieve desired TRL and prepare for potential infusion of technologies into the program.

Within the framework of the ESDMD, funds flow from the M2M Program to EHP to the NASA performing organizations such as JSC's EA, described in the subsequent Section C.

C. Engineering Directorate

EA provides engineering design, development, and test support for major flight programs including Space Shuttle, ISS, and advanced spacecraft. Also, EA performs in-house design, development, manufacturing, and testing of program-funded government-furnished equipment (GFE). EA is organized into seven functional divisions and two offices with specialized disciplines and technical expertise to support the program and project offices. Disciplines within EA include guidance, navigation, and control; electrical power generation, storage, and distribution; all other avionic systems including data management, display and control, and instrumentation; telemetry and communications; structures and materials; thermal protection and thermal control; mechanical systems; propulsion, fluid management, and pyrotechnics; environmental control and life support; spacesuits and extravehicular equipment; aerodynamics, aerothermodynamics, and aeroelasticity; flight software; mission planning and analysis; robotics and advanced automation systems; and overall systems engineering and simulation. In addition, EA maintains expertise in manufacturing and test facilities and computational complexes support the above disciplines.[12] Figure 3 shows the EA patch.

Figure 3. Engineering Directorate Patch

The Crew and Thermal Systems Division (CTSD) is responsible for designing, testing, and developing technology for ECLSS, active thermal control systems for spacecraft and EVA crew members, as well as crew equipment, cold stowage assets/management and spacesuits for both intravehicular activity (IVA) and EVA. CTSD also specializes in both vacuum and thermal vacuum environments including specialized human test facilities. Additional CTSD in-house capabilities include softgoods fabrication, nonmetallic materials development and testing, liquid and gas chemical analysis, and EVA and payload mechanical equipment design.[12,13] Figure 4 show the CTSD patch.

Figure 4. CTSD Patch

EHP is currently CTSD's largest program customer, with scope for the division that includes supporting ISS EVA work, xEVAS development with two vendors, support for an unmanned lunar terrain vehicle (LTV) rover, a pressurized rover (PR), and technology development to enable future missions. CTSD is where the hardware is integrated to enable EVA with multiple partners. [13]

EC5 provides technical subsystem management for Orion Crew Survival Systems and EMU, along with equipment related to both suit systems.[14] Additionally, the branch maintains the technical expertise in the areas of pressure garment system (PGS) and portable life support system (PLSS) along with the test capability for both. The branch was responsible for developing the xEMU government reference design and will continue the technology development to enable future missions.

As shown in Figure 1, the organization framework depicts EC5 as the implementing organization. Therefore, EC5 is considered the supplying organization to create the EVA roadmaps and conduct the work as authorized by the customer organizations (MCO and EHP TI&P). EC5 has been busy creating the EVA roadmaps over the last year in collaboration with EHP TI&P for the PGS and the PLSS with a focus on future missions to Mars. and revealing them to the public in this paper. The EVA roadmaps are discussed in detail in Section IV.

III. Strategy

The NASA Authorization Act of 2022 communicates that the United States will lead the return of humans to the Moon for long-term exploration, followed by human missions to Mars and beyond.[15] "NASA has established the new Moon to Mars Program Office at NASA Headquarters in Washington, DC, to carry out the Agency's human exploration activities at the Moon and Mars for the benefit of humanity."[16] With this program, NASA plans to land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. Artemis III is targeted to launch the first crew to the lunar surface no earlier than September 2026.[17]

"As directed by the 2022 NASA Authorization Act, the Moon to Mars Program Office focuses on hardware development, mission integration, and risk management functions for programs critical to the Agency's exploration approach that uses Artemis missions at the Moon to open a new era of scientific discovery and prepare for human missions to Mars."[16] It is important to reveal what NASA has accomplished thus far. NASA has created a xEMU government reference design and is pursuing commercialization of spacesuits for the future.

A. Exploration EMU Government Reference Design

The xEMU project was devised and executed as a GFE effort. NASA-led teams at JSC conducted much of the engineering and design, in tandem with myriad contractors and vendors on a component-level or part-level basis. The NASA-led teams were also responsible for assembly, testing, and certification. Therefore, the xEMU project was a significant departure from every previous EVA spacesuit development. The capability of NASA in-house expertise, as well as limited appetite for, and funds available to, award large contracts for EMU replacement and early Artemis architecture were significant factors in pursuing this GFE strategy. However, in 2021 the agency decided to implement a strategy to commercialize spacesuit services.[18]

B. Commercial Extravehicular Activity Services

As the Artemis campaign matured and gained inertia, more funding became available as allocated from Congress. The award of the Human Landing System (HLS), coupled with the recent successes in the Commercial Cargo and Crew programs, were catalysts for a change to Exploration EVA procurement strategy. Over the summer of 2021, a Request for Information (RFI) and Request for Proposal (RFP) were posted to solicit potential vendors, or vendor teams, to provide an ISS EMU spacesuit replacement and the Artemis lunar spacesuit as a service wholly developed, certified, and owned by the vendor. Under this solicitation, called xEVAS, NASA pays a fixed price for a vendor to provide an EVA service to support NASA missions similarly to how commercial crew vendors provide a launch and ISS ferry service. The vendors are responsible for the spacesuit design and fabrication and maintain ownership of the hardware. This means the vendors will also be required to provide spacesuit maintenance, logistics, and sustaining engineering for their hardware; this historically fell under NASA's purview or was executed on postdelivery sustaining engineering contracts. Under the xEVAS contract, the complete xEMU reference design, NASA testing facilities, and NASA xEMU personnel have been made available for the vendor to use and leverage how they deem appropriate to meet technical and deliverable requirements.

In the summer of 2022, the government awarded the xEVAS contract to two vendors; Axiom Space and Collins Aerospace.[18] Axiom Space was issued a task order in September 2022 to deliver the EVA system for the Artemis III mission. In December 2022, Collins Aerospace was issued a task order to develop an EVA system for the ISS and complete a Critical Design Review in pursuit of that mission. The xEVAS solicitation is written in a way that the government has the capability to add future additional vendors as it desires. NASA's Advanced Suit Team is currently supporting both task orders through mechanisms identified in the xEVAS contract.

The task orders on xEVAS have been awarded only for Artemis III and no later. Therefore, the technology development and detailed design to enable the sustaining class lunar missions, as well as later missions to Mars, are still under NASA's purview and responsibility. For EVA, a sustaining class lunar mission is one that reuses the spacesuit for multiple missions. Furthermore, given the maturing design of the xEVAS vendors, clearly defined infusion paths are important to ensure that NASA technology investments can be leveraged in future flight designs for these later missions.

It is within this context that EC5, in collaboration with the EHP TI&P Office, developed and continues to nurture EVA technology roadmaps for the PGS and PLSS.

IV. Extravehicular Activity Roadmaps

The EVA roadmaps' goals are to enable EVA operations on Mars, using lunar surface opportunities for demonstration as appropriate, to facilitate risk mitigation for "sustained lunar" mission phase, and to increase life robustness for long-duration lunar missions. History has demonstrated that development of an exploration class lunar EVA spacesuit takes years; it is presumed that the same will be true for a Mars exploration EVA spacesuit. The progression of flight demonstrations from ISS, to boots on the Moon, to sustained lunar will serve as precursors and lessons learned for Mars missions. It is further expected that investments in Mars-enabling capabilities can improve lunar EVA performance.

The Mars EVA spacesuit system will be required to egress and ingress habitable vehicles and provide life support, thermal control, protection from the environment, waste management, hydration and in-suit nutrition, communications, and mobility features designed to interact with spacecraft interfaces and supporting tools and equipment such that exploration, science, construction, and vehicle maintenance tasks can be done safely and effectively.[6]

An EVA spacesuit typically consists of a PGS, a PLSS, and an informatics system. The EVA roadmaps in this paper are segmented into PGS and PLSS roadmaps. The informatics roadmap will be documented in a separate paper. Roadmaps serve as a means to identify and communicate capability gaps and the strategy for closing such gaps to accomplish mission objectives by reducing program and project risks. Each EVA roadmap is organized by capability gap (or group of gaps), follows an FY timeline, and documents any additional information on key performance parameters, milestones, decision points, or important details. The PGS and PLSS roadmaps are designed based on a Gantt chart style, using icon shapes and sizes to represent details such as funding status, funding source, and duration.

A. Environment

Surface EVA exploration is significantly different from microgravity EVAs. The challenges include dust mitigation, operation in partial gravity, mobility and habitation considerations, site planning, and contingency scenarios. Surface EVAs are faced with limitations to mass, power, volume, the environment, and physical operations that occur on the Moon and, to even greater extent, on Mars.[19]

The primary function of the EVA spacesuit system is to protect the CM from the various environments encountered during a Mars mission, independent of a pressurized cabin. The Mars EVA spacesuit must provide sufficient safety, mobility, communications, and comfort for crew to perform their duties inside or outside a vehicle for up to a full workday.[6]

The Mars EVA spacesuit, intended for Martian surface operations, will be different from a lunar spacesuit. The Mars spacesuit will be unique because of gravity and environmental differences and planetary protection strategies. Martian gravity is higher than on the Moon. The resulting increased weight calls for improved mobility and system mass reductions. The thin Martian atmosphere and the predominance of carbon dioxide in the atmosphere will require changes in life support system operation.[6]

B. Pressure Garment System Roadmap

The xEMU project and subsequently the Exploration Pressure Garment System (xPGS) evolved over time. In 2019, the xEMU demonstration pressure garment architecture was released, which included a new Hard Upper Torso, Shoulders, Helmet, and Extra-Vehicular Visor Assembly (EVVA), while reusing the EMU lower torso, arms, gloves, and boots. The xEMU demo project covered the manufacturing of a single PLSS, PGS and demonstration on the ISS. The project's intent was to conduct a flight demonstration of new technologies and then transition fleet manufacturing and sustaining to a prime contractor to replace the EMU. However, the xEMU project was identified as the best path to manufacture spacesuits for the initial lunar mission, projected to occur near the lunar south pole. As a result, the xEMU project transitioned into a multiple program flight project that included development of both a spacesuit for the ISS and for the first Artemis lunar surface mission. This transition to a multi-program, multi-destination system was a significant change in project scope and requirements that resulted in changes to the xPGS's architecture. These changes included improved lower torso mobility, lunar boots that meet challenging thermal requirements of the permanently shadowed regions of the Moon, a new environmental protection garment (EPG) for dust protection, and enhanced cycle life performance over the needs of the ISS. The xPGS design verification testing unit, the pressure garment of the xEMU is shown in Figure 5. For much more detail on the design of the xPGS and its components, refer to the various manuscripts published in ICES 2022. The PGS roadmap is divided into Mars-enabling and sustaining lunar technologies. These are detailed in the sections below.

Figure 5. xPGS Assembly

1. Scope of Mars vs. Sustaining Lunar

The PGS roadmap has two primary technical mission scopes. The first scope is Mars, which identifies and maps Mars-enabling technologies that may not or will not be completed as part of a sustaining lunar EVA spacesuit architecture. For example, given the unique thermal environment of Mars, a large emphasis of the Mars roadmap is Mars-specific thermal insulation and integration into a Mars EPG. The second scope is sustaining lunar, which identifies and maps technologies that are required to enable sustaining-class Artemis missions. For example, long-term durability, cycle life and maintainability are all aspects of an EVA spacesuit that enable sustaining mission profiles.

One aspect of PGS design is that there is significant overlap between sustaining lunar and Mars. Despite differences in dust morphology, gravity, thermal environment, and operational concepts, much of the underlying design drivers are the same as they relate to pressurized mobility and comfort, durability, cycle life, and maintainability. The structure of the roadmap is designed to accommodate this overlap and communicate the technology development needs more clearly and logically.

2. PGS Roadmap

The PGS roadmap is displayed in Figure 6 and Figure 7.

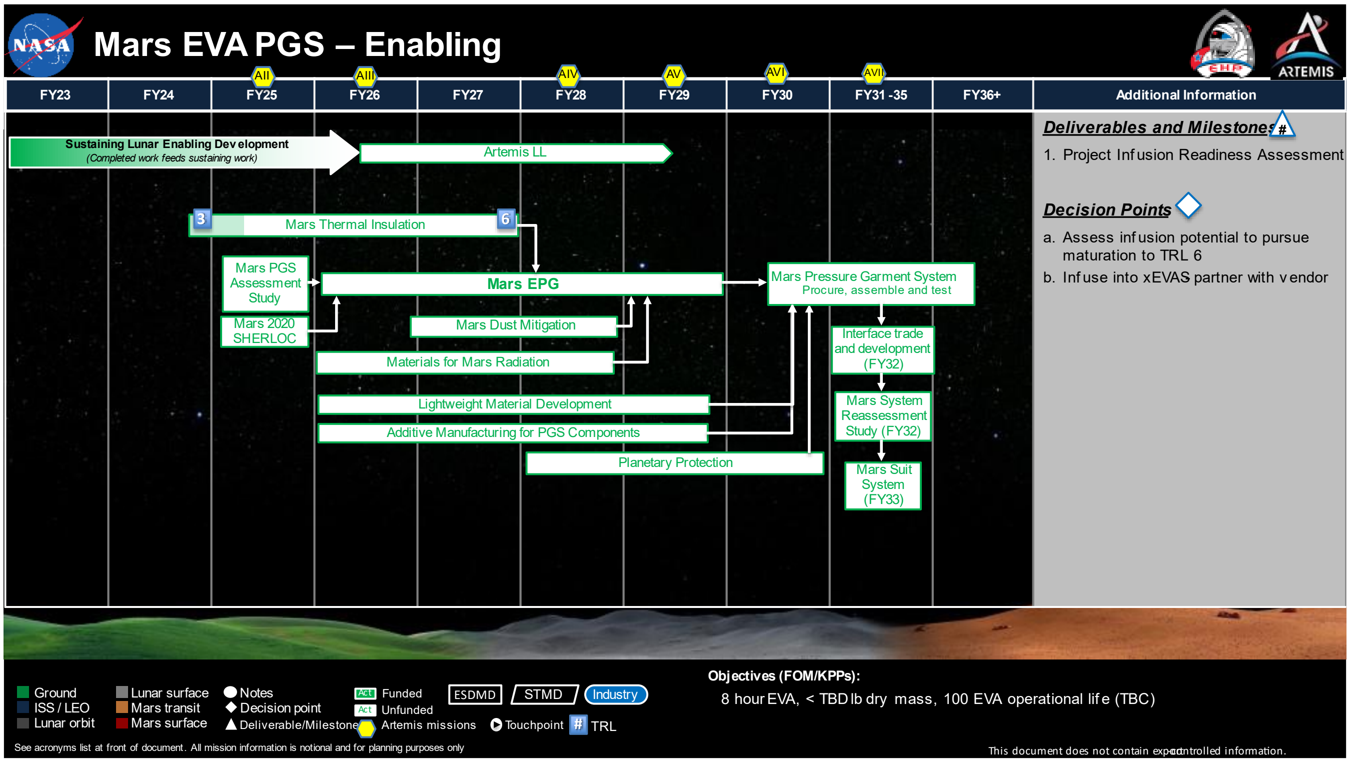


Figure 6. Mars EVA PGS - Enabling Roadmap.

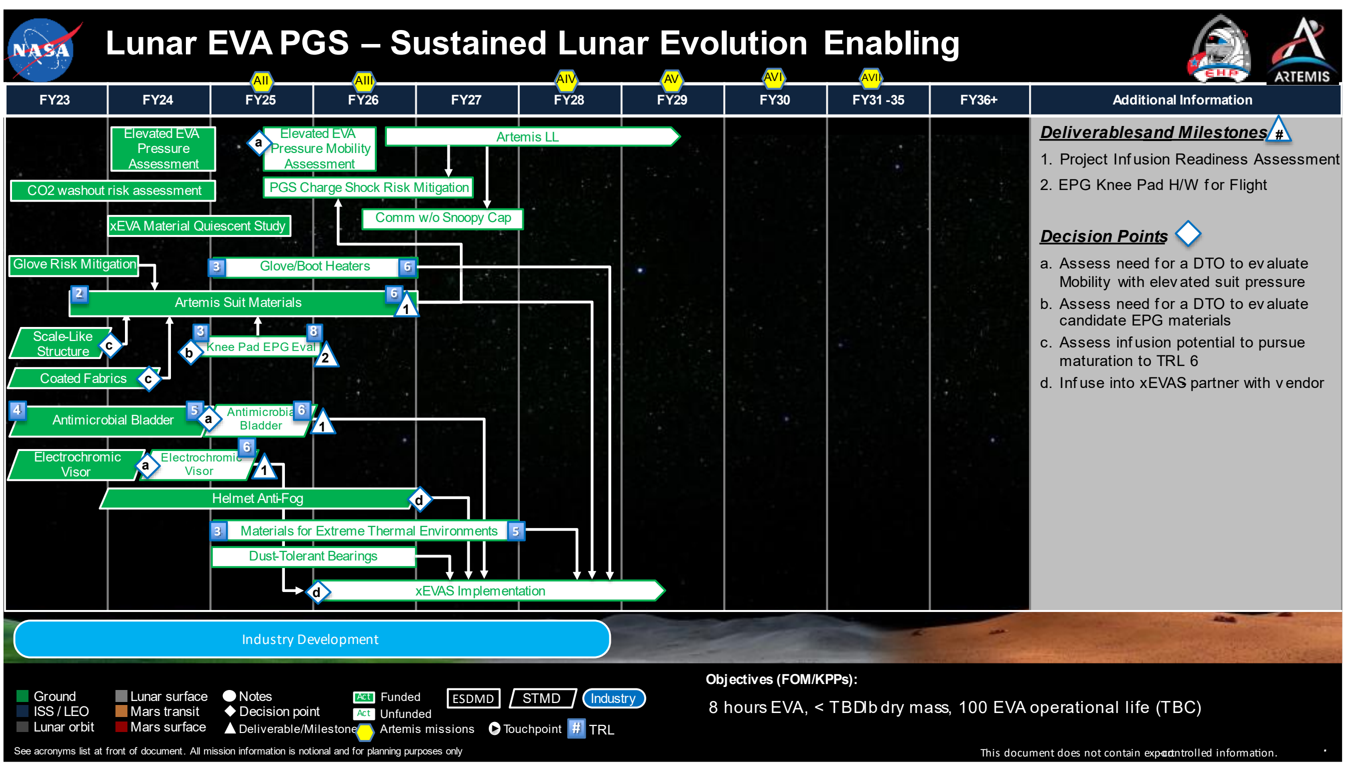


Figure 7. Lunar EVA PGS – Sustained Enabling Roadmap.

C. Portable Life Support System Roadmap

An EVA spacesuit is an integrated spacecraft for a single person and has multiple complicated functions. The PLSS includes the functions of oxygen (O_2) supply, ventilation, thermal control, avionics, and power. Because of extreme limitations with on-suit mass and volume to provide these functions, a PLSS becomes a highly integrated system. The PLSS has key interfaces with other vehicles in a mission architecture to do consumables recharge (water, oxygen, and power), communications, power, and structural mounting interfaces.

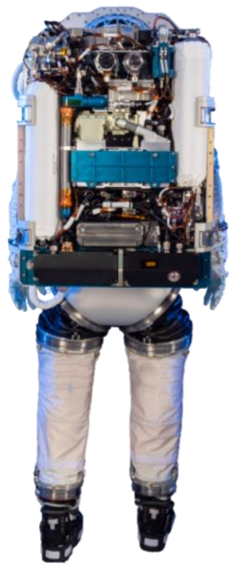


Figure 8. xEMU PLSS

The PLSS, as designed in the xEMU government reference design, is shown in Figure 8. The PLSS is contained in a rectangular package that adheres to the back of the spacesuit.

As opposed to the ISS EMU PLSS operation, the future PLSS will be required to operate farther from Earth, for longer missions, with fewer opportunities for refurbishment on the ground, and in new environments on the Moon and Mars. The PLSS roadmap starts with addressing the current risks with state-of-the-art designs and technologies, then targets gaps that will need to be filled to meet the challenging new missions planned for future spacesuits.

The PLSS roadmap has three goals: 1) enable EVA operations on Mars, using lunar surface opportunities for demonstration as appropriate; 2) facilitate risk mitigation for "sustained lunar" mission; and 3) increase life robustness for long-duration lunar missions.

The development of a Mars EVA spacesuit system will take years. A 2024 start is needed to meet the NASA M2M timeline for Mars surface exploration in the late 2030s.[6] The PLSS roadmap tracks PLSS technologies applicable to EVA spacesuits at a functional capability-level and does not capture in detail maturation needs across all potentially enabling component subsystems (e. g., thermal, power, avionics). This roadmap presents an approach dependent on multiple funding sources and mechanism, not solely an EHP-funded approach.

The PLSS roadmap has been divided into four swim lanes: 1) Cross-Subsystem & System Architecture Development (Figure 9); 2) O_2 Supply & Ventilation (Figures 10a and 10b); 3) Thermal Control (Figure 11); and 4) Avionics & Power (Figure 12).

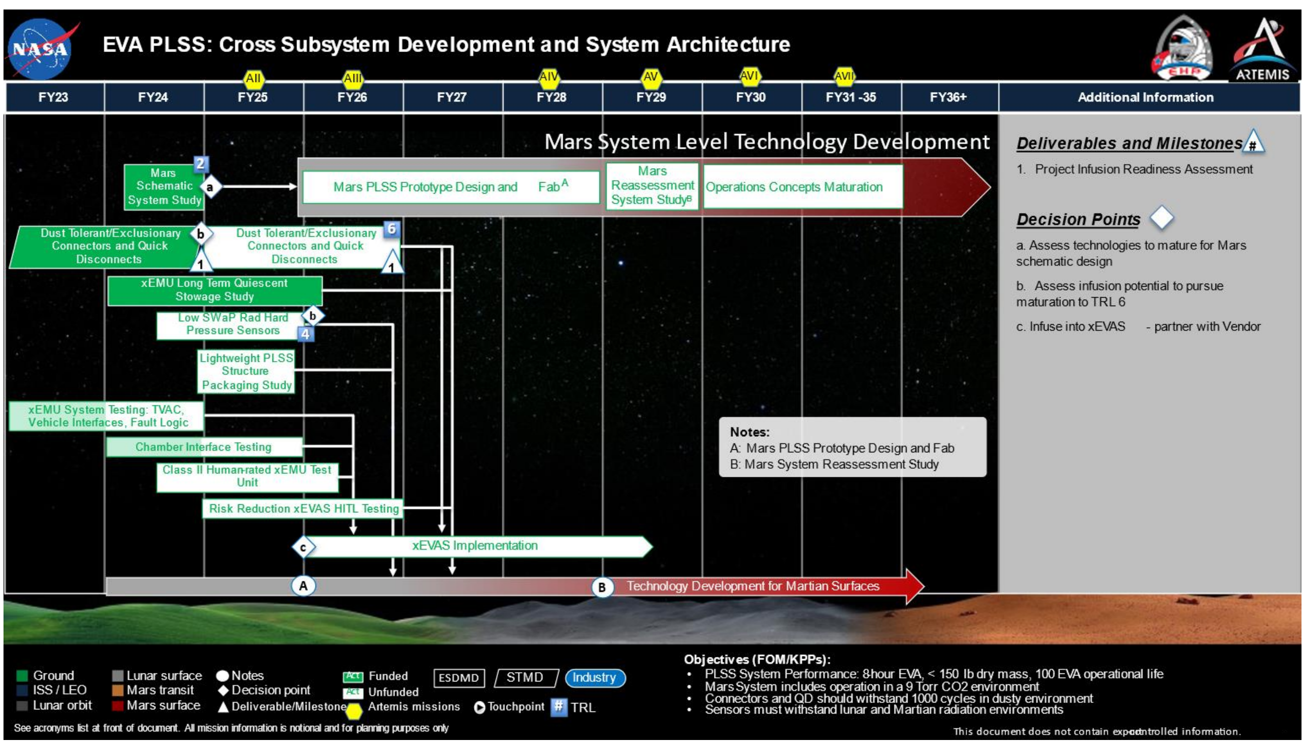
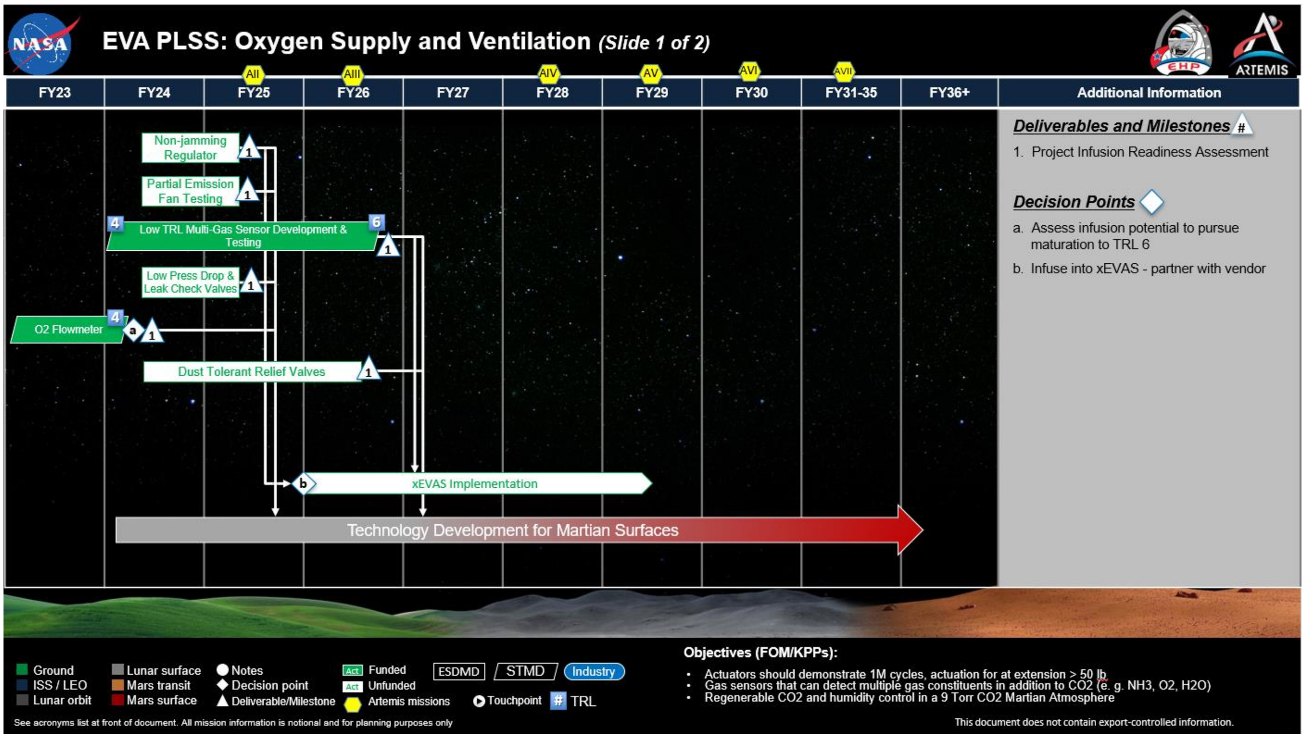
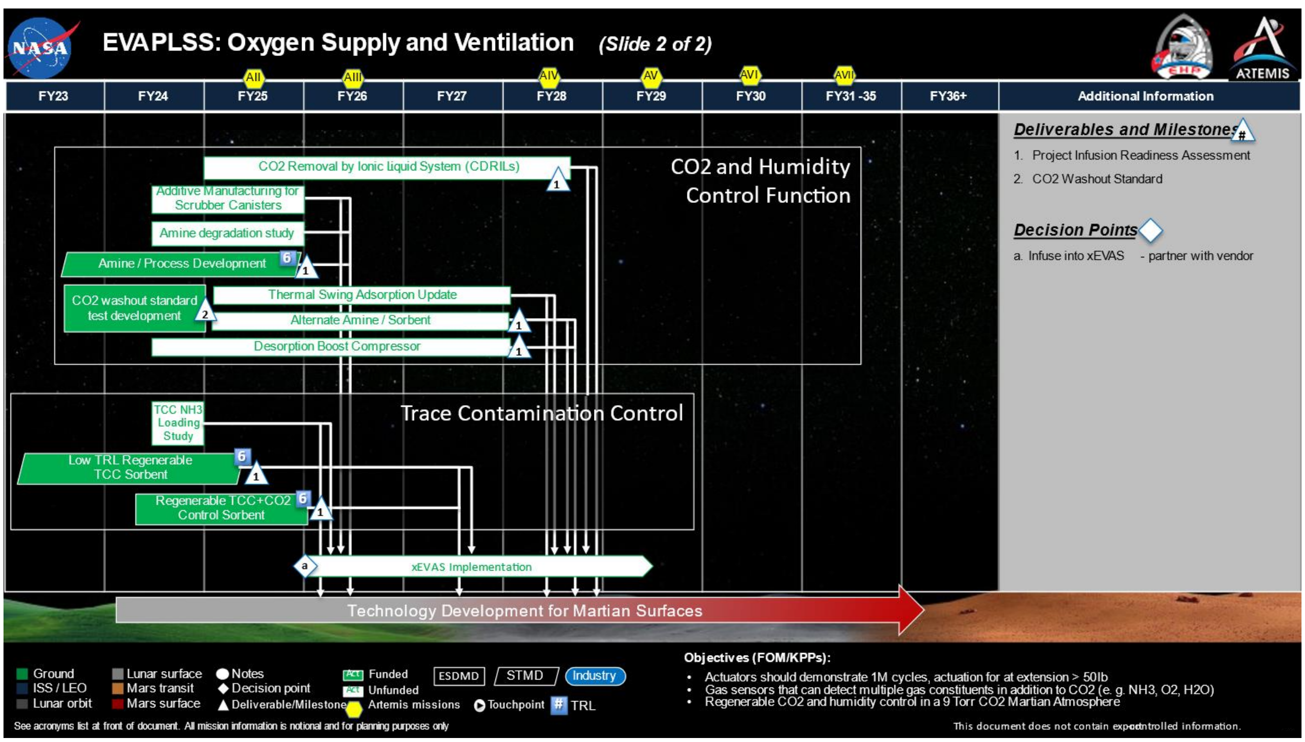


Figure 9. Cross Subsystem & System Architecture Development.



a)



b)

Figure 10. Oxygen Supply and Ventilation. ***a) Slide 1 of 2 b) Slide 2 of 2***

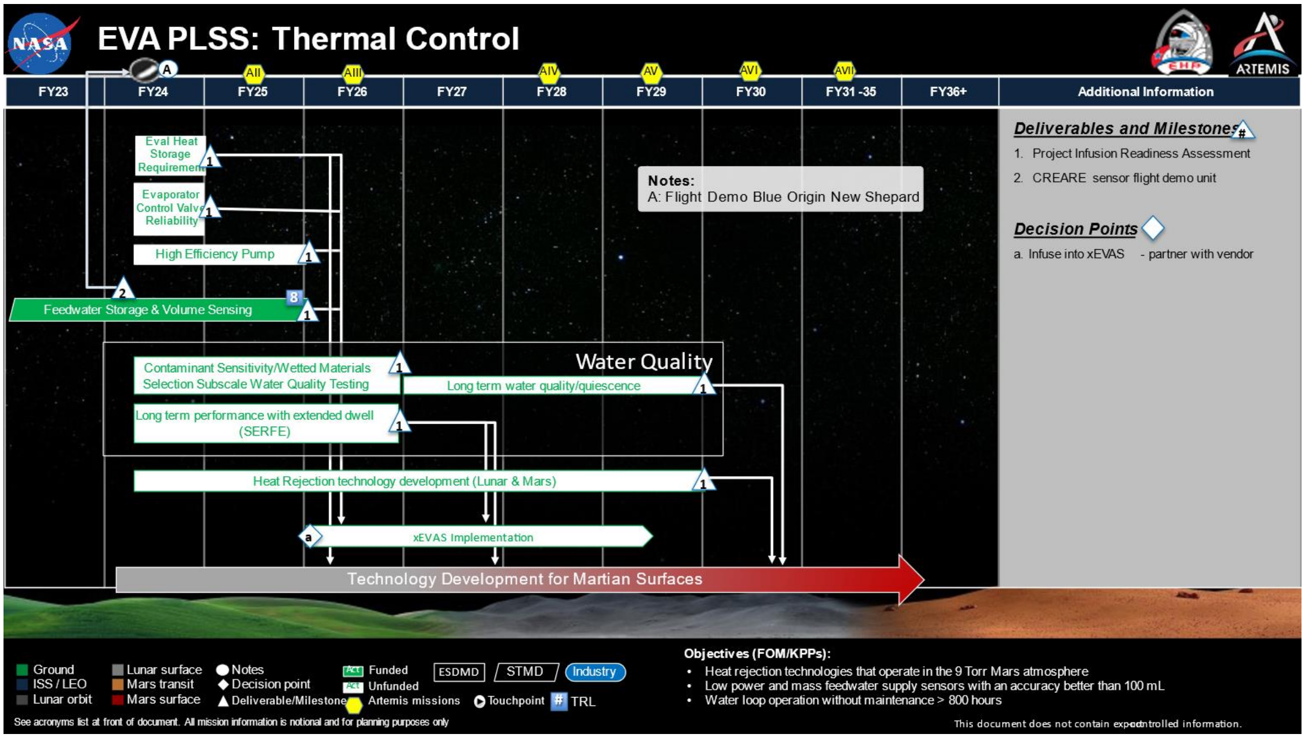


Figure 11. Thermal Control.

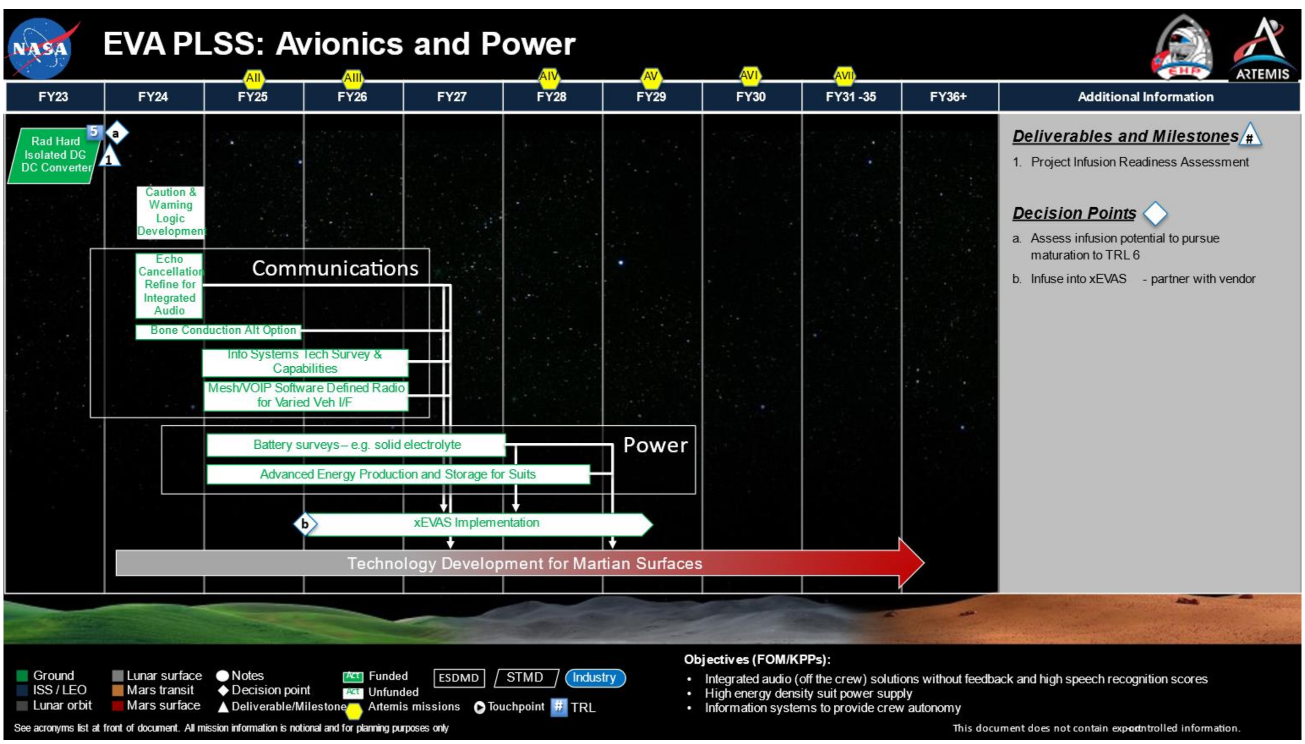


Figure 12. Avionics and Power.

1. *Cross-Subsystem & System Architecture Development*

These criteria either involve system integration or common components. As individual technologies are developed, a system architecture trade must be done to evaluate how they function as part of the larger life support system. Periodic system hardware demonstrations must be performed to fully assess the merits of specific technologies and system designs. The end goal is to focus on closing the gap of fully packaged, integrated, and functional PLSS.

2. *O_2 Supply & Ventilation*

The PLSS must store and provide O_2 to crew members at appropriate spacesuit pressures for the duration of an EVA. The PLSS must circulate O_2 through the spacesuit and remove constituents like carbon dioxide, humidity, and trace contaminants.

3. *Thermal Control*

The PLSS provides cooling to the crew and spacesuit hardware. Development includes Liquid Cooling Garments, studies on long duration water and materials compatibility, heat rejection technologies that do not use consumables or can be used in a Martian environment, and thermal control valves.

4. *Avionics & Power*

Radiation-hardened electrical and electronics engineering parts are needed to provide low size, weight, and power avionics to distribute power, drive motors and actuators, read telemetry and provide spacesuit communication. Power to the PLSS is currently provided by batteries. Caution & warning, telemetry, and voice communication form a discipline and electronic ease of integration. However, for Mars application, these technical disciplines may not necessarily be integrated directly into the PLSS architecture.

IV. Conclusion

EVA spacesuits symbolize human space exploration. Development of a Mars EVA spacesuit is necessary to survive the Martian environment that capitalizes on the lessons learned from the lunar surface and microgravity destinations. History has demonstrated that substantial time is needed to develop new technologies, integrate them into a wearable spacecraft, and operate them safely. Identifying nascent technologies that show promise to mature into flightworthy hardware is critical to the success of the M2M Program. The roadmaps presented in this paper graphically represent the current and notional gap closure activities to advance from state-of-the-art capabilities necessary for a Mars EVA spacesuit system.

EVA technology development is an iterative process built on lessons learned whereby those lessons are translated into practice. Lunar development efforts began with a schematic study, to bread-board, to initial packaging, to detailed packaging, to xEMU government reference design, and now to the xEVAS vendors. Multiple iterations of new component technologies have resulted in successful infusion from the Advanced Extravehicular Mobility Unit to the xEMU and xEVAS vendors. The EVA roadmaps revealed in this paper set the stage for future technology development and will evolve depending on the program's goals and objectives for future missions.

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