

NASA Extravehicular Activity Technology Roadmaps for Exploration

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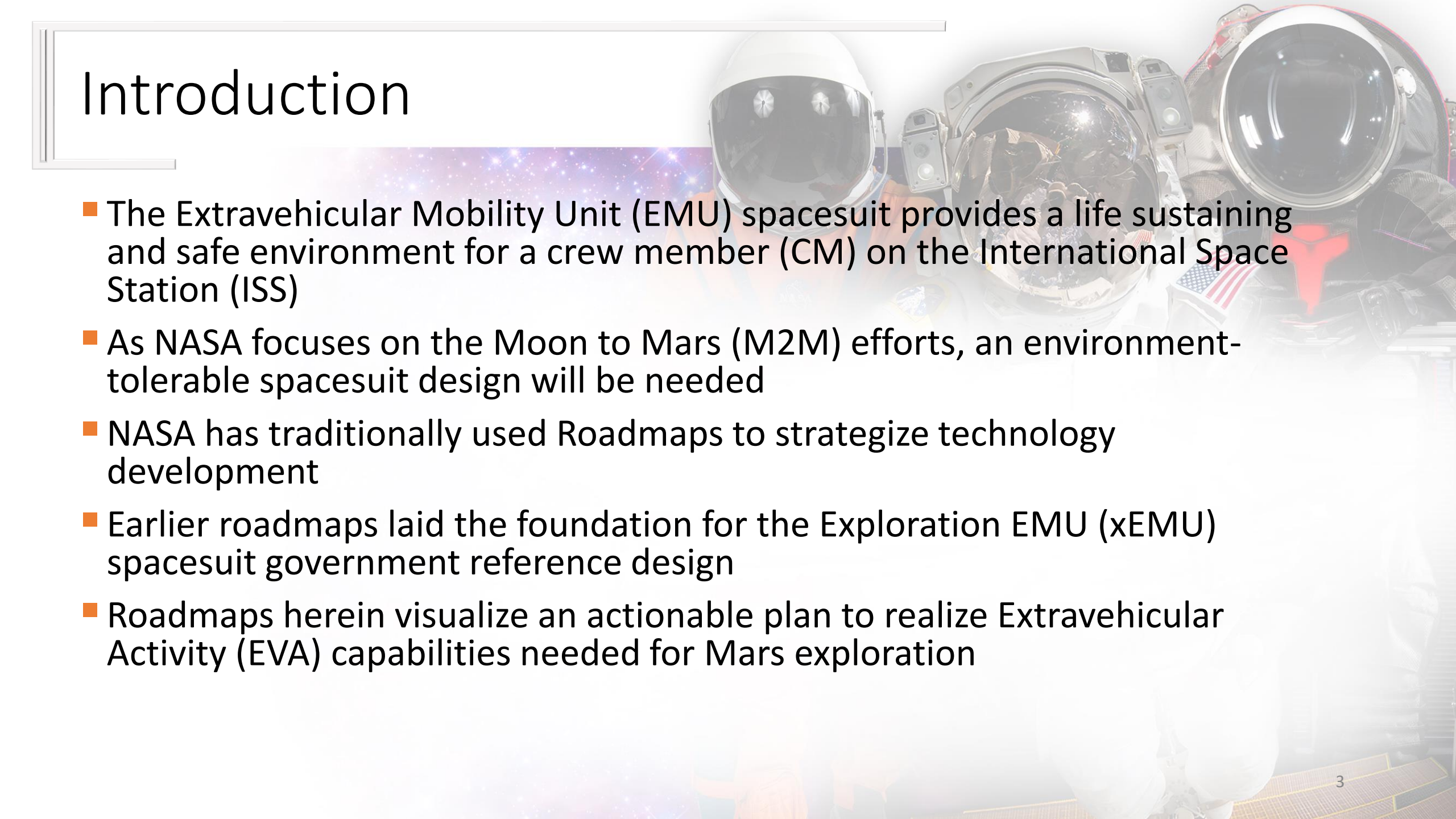
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Overview

- Introduction
- Organizational Framework
- Strategy
- Extravehicular Activity Roadmaps
 - Environment
 - Pressure Garment System Roadmap
 - Portable Life Support System Roadmap
- Conclusion
- Acknowledgements



Introduction



- The Extravehicular Mobility Unit (EMU) spacesuit provides a life sustaining and safe environment for a crew member (CM) on the International Space Station (ISS)
- As NASA focuses on the Moon to Mars (M2M) efforts, an environment-tolerable spacesuit design will be needed
- NASA has traditionally used Roadmaps to strategize technology development
- Earlier roadmaps laid the foundation for the Exploration EMU (xEMU) spacesuit government reference design
- Roadmaps herein visualize an actionable plan to realize Extravehicular Activity (EVA) capabilities needed for Mars exploration

Organizational Framework

- Many programs facilitated the development of the xEMU Spacesuit
 - Constellation Program
 - Exploration Technology Development Program
 - Enabling Technology Development and Demonstration Program
 - Advanced Exploration Systems Program
 - Space Technology Mission Directorate
 - Game Changing Development Program
 - Small Business Innovative Research (SBIR)/Small Business Technology Transfer (STTR)
 - Office of Chief Technology
 - EVA & Human Surface Mobility Program (EHP)
- Mission strategies changed over time precluding an individual program from funding the xEMU development to ISS demonstration
- NASA is currently leading commercially developed spacesuits for ISS and lunar surface missions
- As NASA pursues future missions to Mars, advancing the technology even further is dependent on strategic vision and programmatic support
- M2M Architecture Definition Document (ADD) establishes strategic framework and objectives for human exploration missions, including EVA system capabilities

Organizational Framework

Mars Campaign Office (MCO)

- Matures exploration capabilities & transit solutions to enable future human missions to Mars

EHP Technology Integration & Partnerships Office (TI&P)

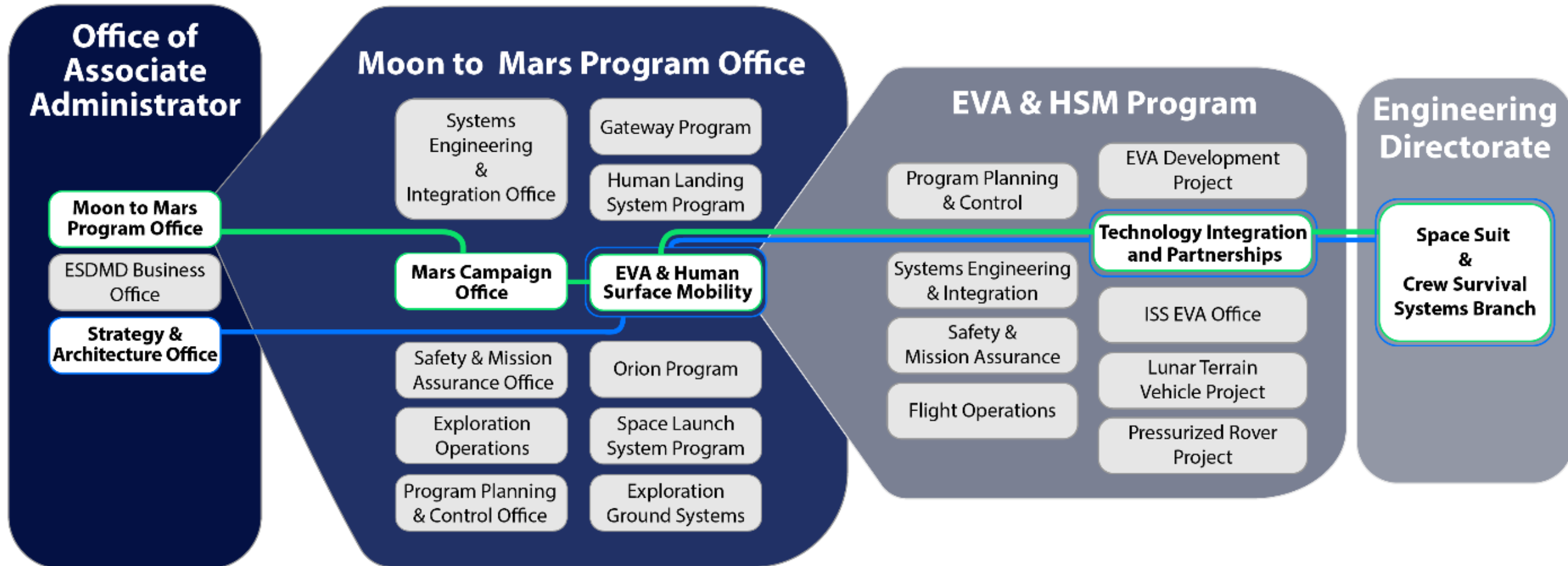
- EHP portfolio includes:
 - EVAs & EVA hardware
 - Rovers
 - Lunar surface implementation of the M2M architecture
- Collaborates across the agency and with industry
- Stakeholder for Roadmaps

Engineering Directorate's Crew and Thermal Systems Division (CTSD) Space Suit & Crew Survival Systems Branch (EC5)

- Engineering Directorate provides engineering design, development test, and evaluation (DDT&E) support to the major programs
 - Technical Authority for EVA Development
- CTSD/EC5
 - EVA Spacesuit and Intravehicular Activity (IVA) Technical expertise
 - Specialize:
 - Pressure garment systems (PGS)
 - Portable life support systems (PLSS)
 - Crew survival systems development

- An organizational framework depicts the relationships necessary to formulate a vision and plan

Organizational Framework

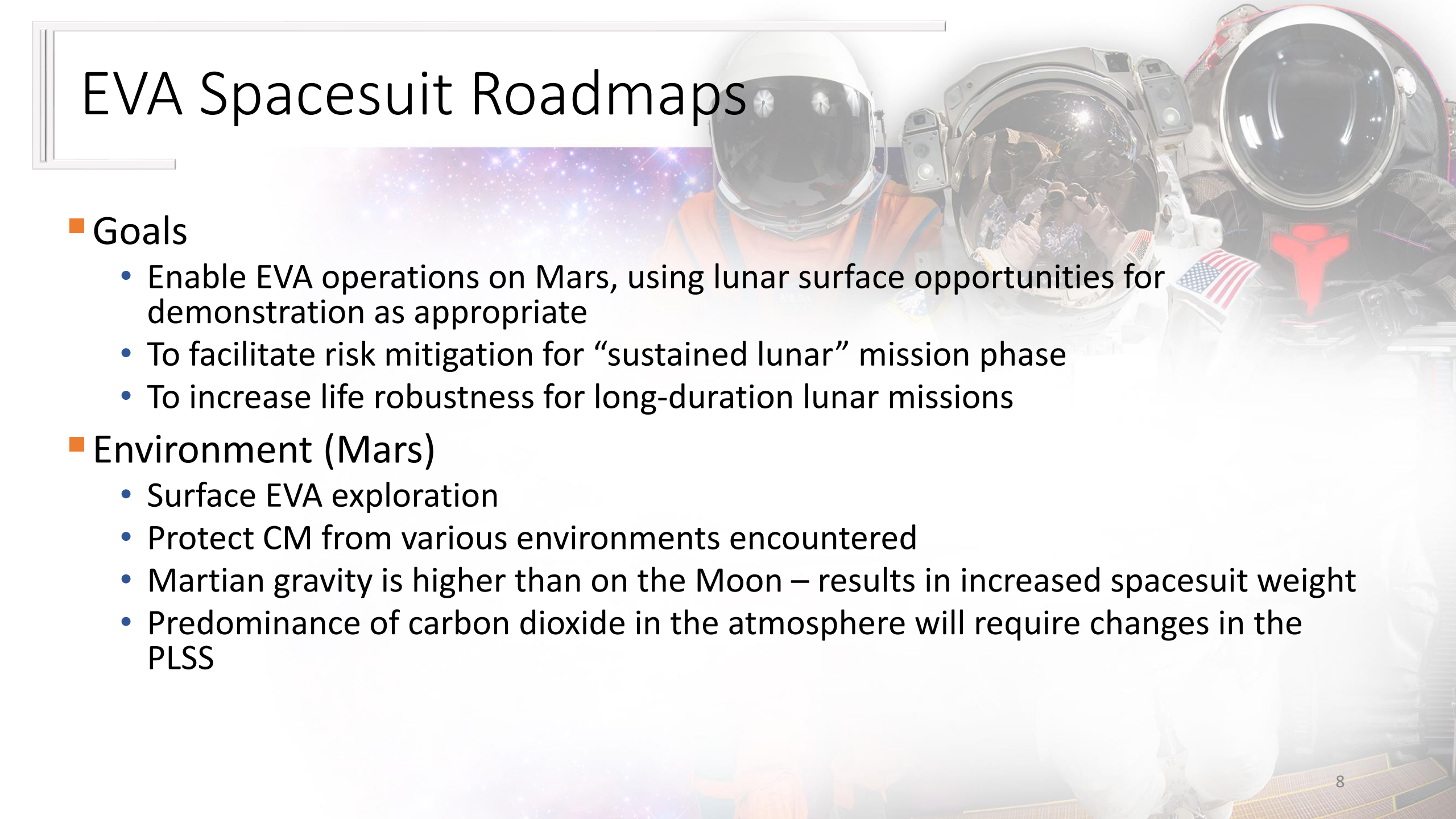


Strategy



- NASA Authorization Act of 2022 – return humans to the Moon for long-term duration and human missions to Mars and beyond
- Exploration EMU Spacesuit Government Reference Design
 - xEMU Project was executed as a Government Furnished Equipment (GFE)
 - Designed, developed, and tested in-house
- Commercial Extravehicular Activity Services
 - Summer 2022 – NASA awarded the Exploration EVA Services (xEVAS) to two vendors
 - Axiom Space
 - Collins Aerospace

EVA Spacesuit Roadmaps

The background of the slide features a composite image of three astronauts in different spacesuits. On the left, an astronaut in an orange suit is partially visible. In the center, an astronaut in a white suit is shown from the chest up, holding a camera. On the right, another astronaut in a white suit with a prominent red 'Y' logo on the chest is visible. The background is a deep space scene with a purple and blue nebula and numerous stars.

■ Goals

- Enable EVA operations on Mars, using lunar surface opportunities for demonstration as appropriate
- To facilitate risk mitigation for “sustained lunar” mission phase
- To increase life robustness for long-duration lunar missions

■ Environment (Mars)

- Surface EVA exploration
- Protect CM from various environments encountered
- Martian gravity is higher than on the Moon – results in increased spacesuit weight
- Predominance of carbon dioxide in the atmosphere will require changes in the PLSS

EVA PGS Roadmap



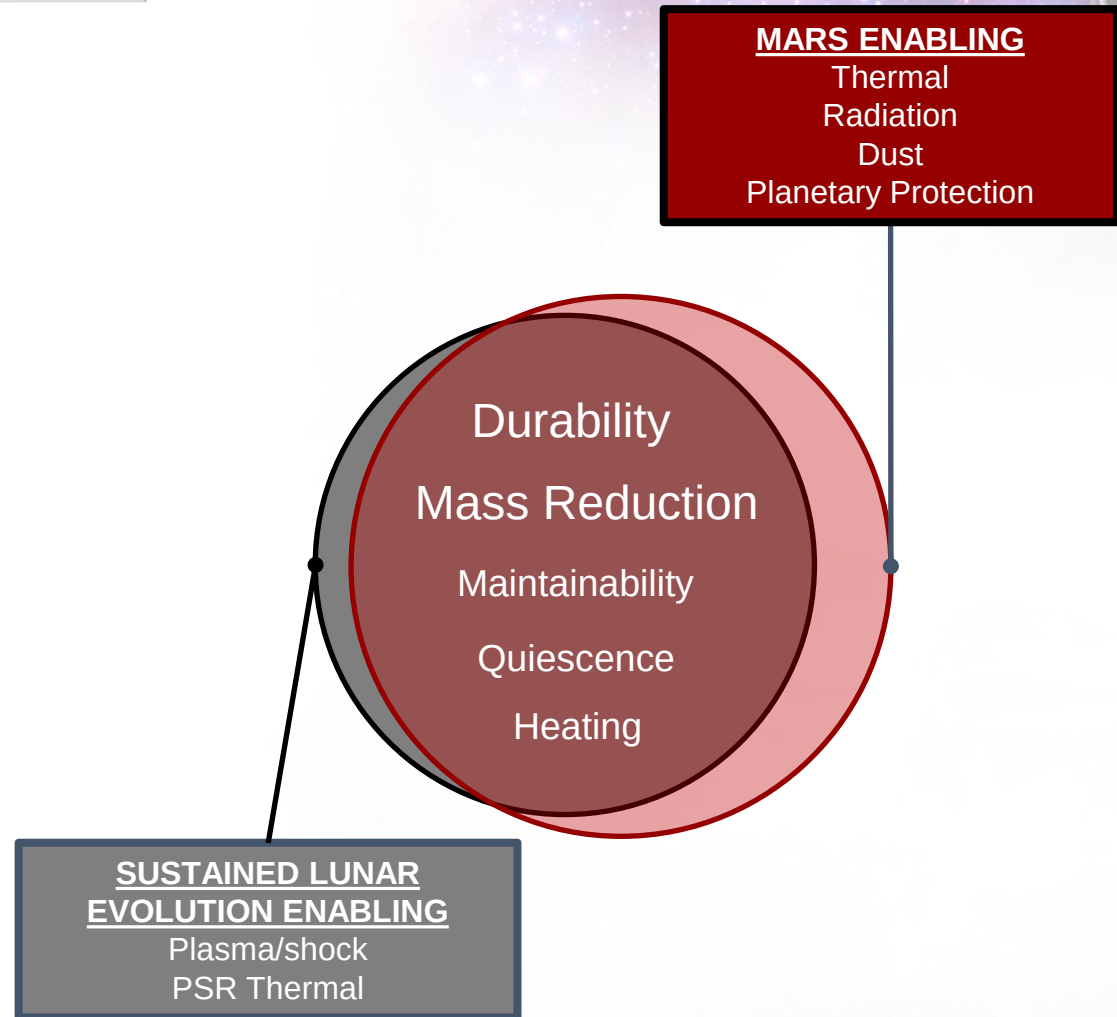
xPGS Assembly

■ Scope

- Organized by mission applicability not technology areas
- Mars EVA PGS - Enabling
 - Capabilities and technologies that are unique to Mars EVA
 - Capabilities and technologies that enable Mars EVA and enhance lunar
 - Enhance logistics, crew safety, and/or performance
- Lunar EVA PGS – Sustained Lunar Evolution Enabling*
 - Capabilities & technologies required to enable a long duration lunar mission*
 - Supporting durability, maintainability, and cycle life
 - Enabling broader operational range

*Reference: NASA Report, “Exploration Systems Development Mission Directorate (ESDMD) Moon-to-Mars Architecture Definition Document,” NASA/TP-20230002706, April 2023, URL: <https://ntrs.nasa.gov/citations/20230002706>

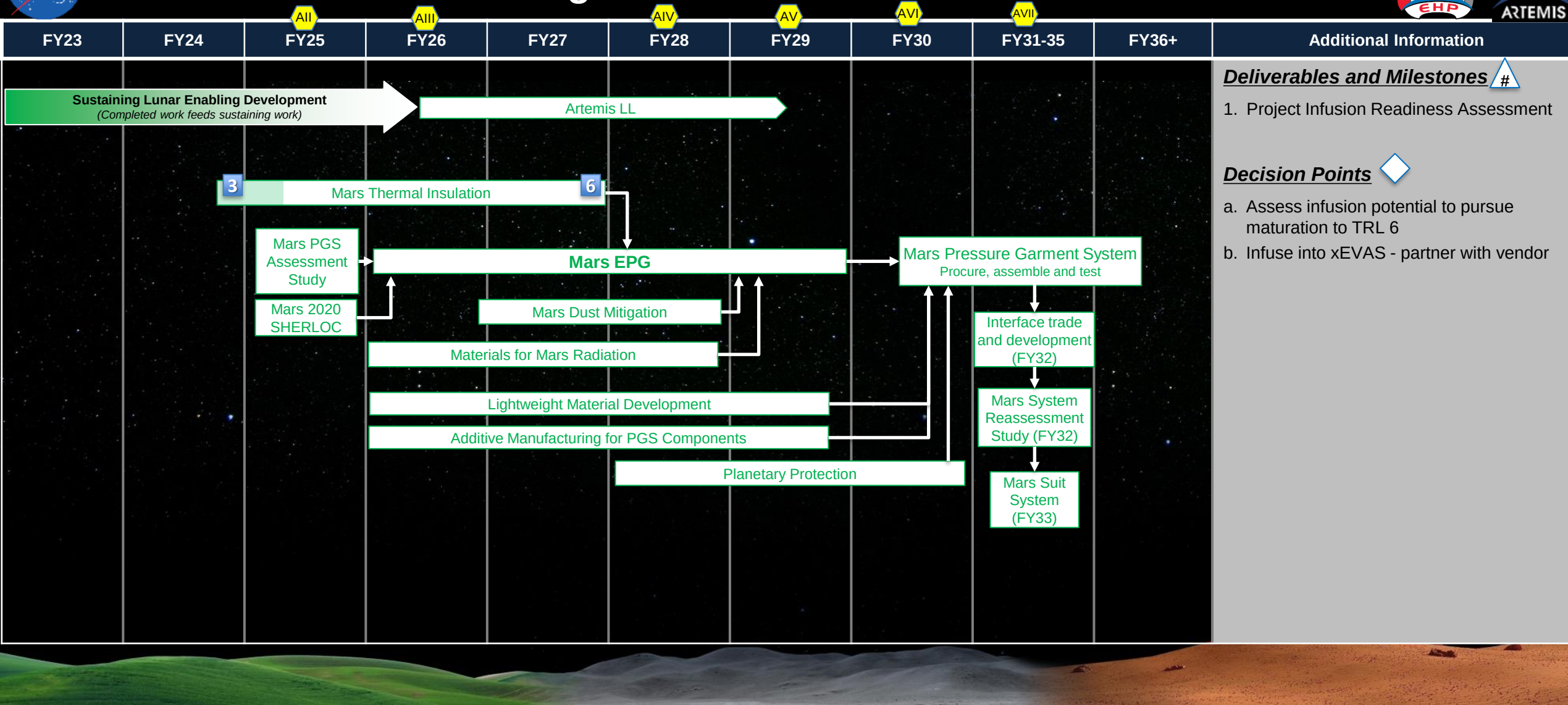
EVA PGS Roadmap



The overlapping area illustrates the significant quantity of Mars capability needs that will enhance lunar exploration.



Mars EVA PGS – Enabling



Ground

ISS / LEO

Lunar orbit

Lunar surface

Mars transit

Mars surface

Notes

Decision point

Deliverable/Milestone

Funded

Unfunded

Artemis missions

ESDMD

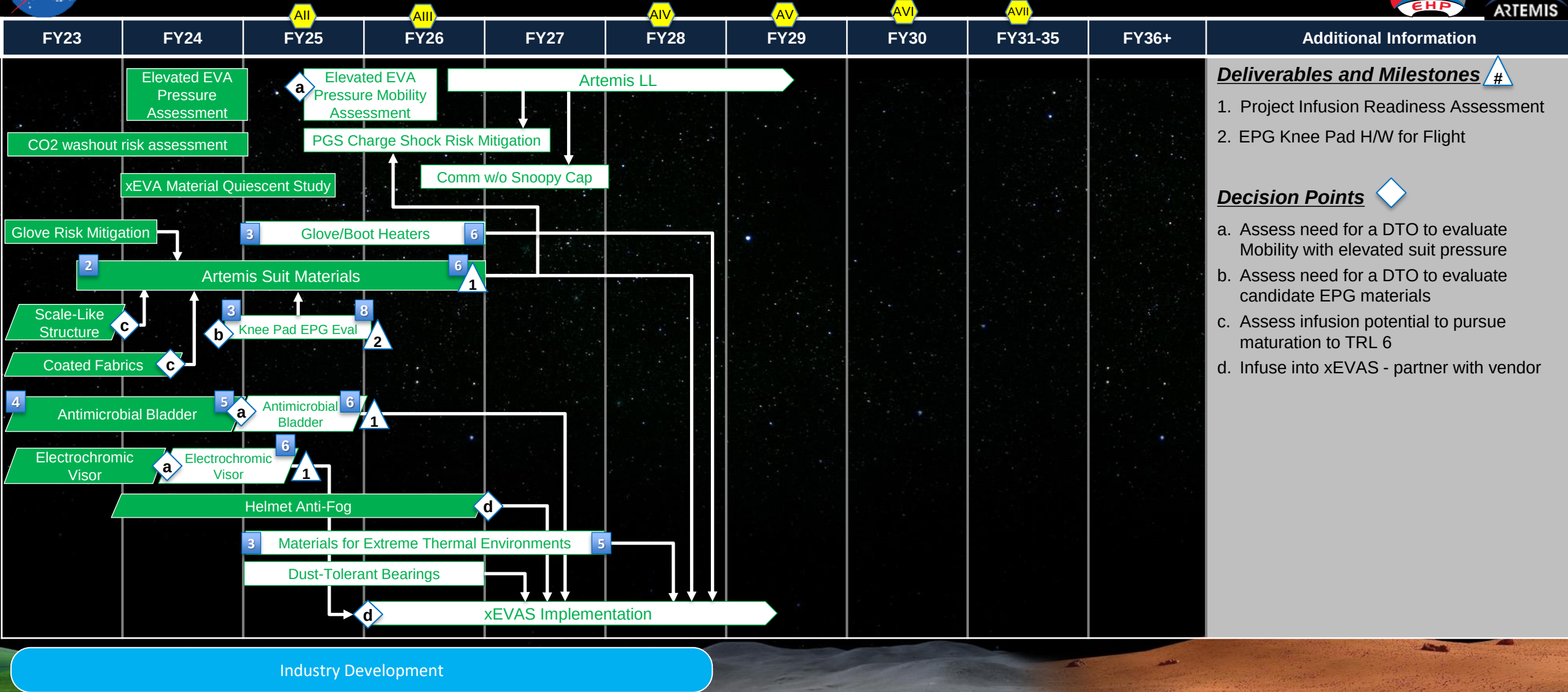
STMD

Industry

Touchpoint

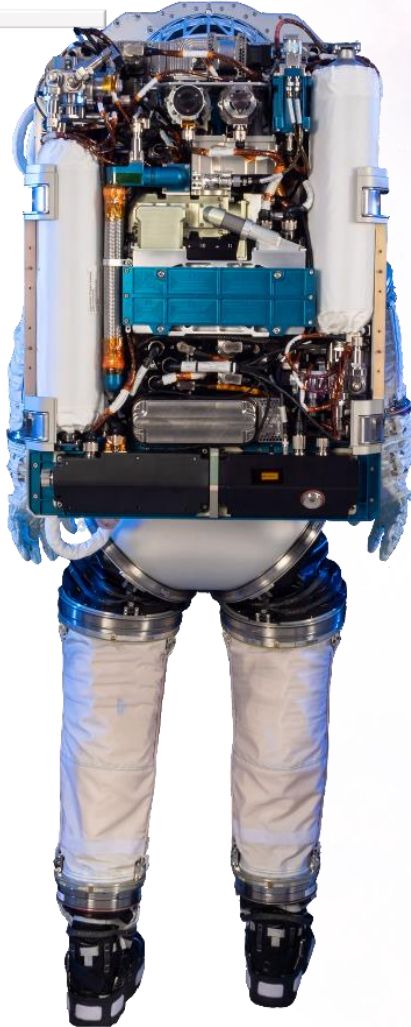
TRL

Objectives (FOM/KPPs):
8 hour EVA, < TBD lb dry mass, 100 EVA operational life (TBC)



8 hours EVA, < TBD lb dry mass, 100 EVA operational life (TBC)

EVA PLSS Roadmap



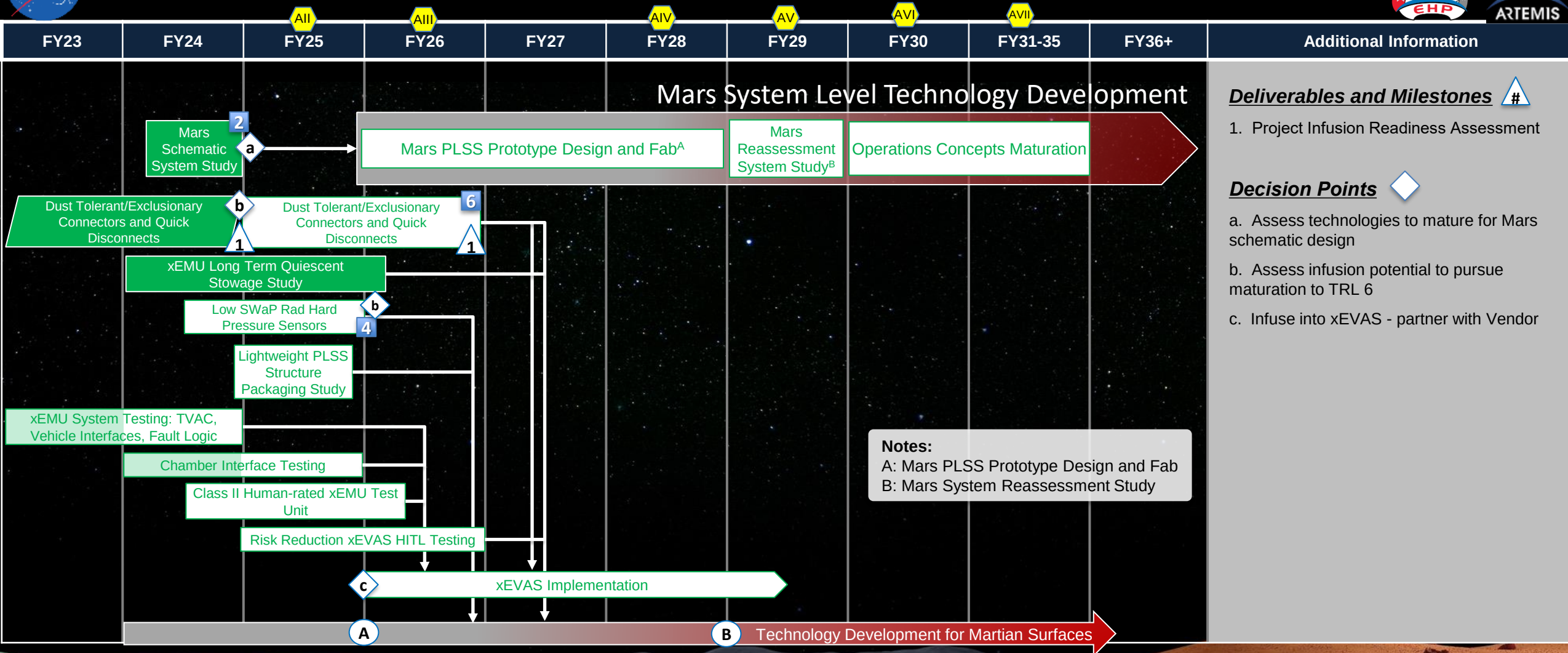
xEMU PLSS

■ Scope

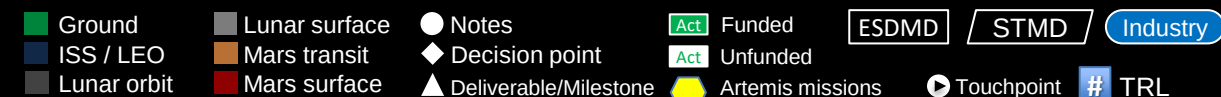
- PLSS is an integrated system packaged into a backpack worn by a CM
- Integration of sub-systems and cross sub-systems is necessary to validate capability
- Culmination of this PLSS integration is in the Mars PLSS Prototype and Mars System Re-assessment Study
- Divided into 4 swim lanes:
 1. Cross-Subsystem & System Architecture Development
 2. O₂ Supply & Ventilation
 3. Thermal Control
 4. Avionics & Power



EVA PLSS: Cross Subsystem Development and System Architecture



Notes:
A: Mars PLSS Prototype Design and Fab
B: Mars System Reassessment Study

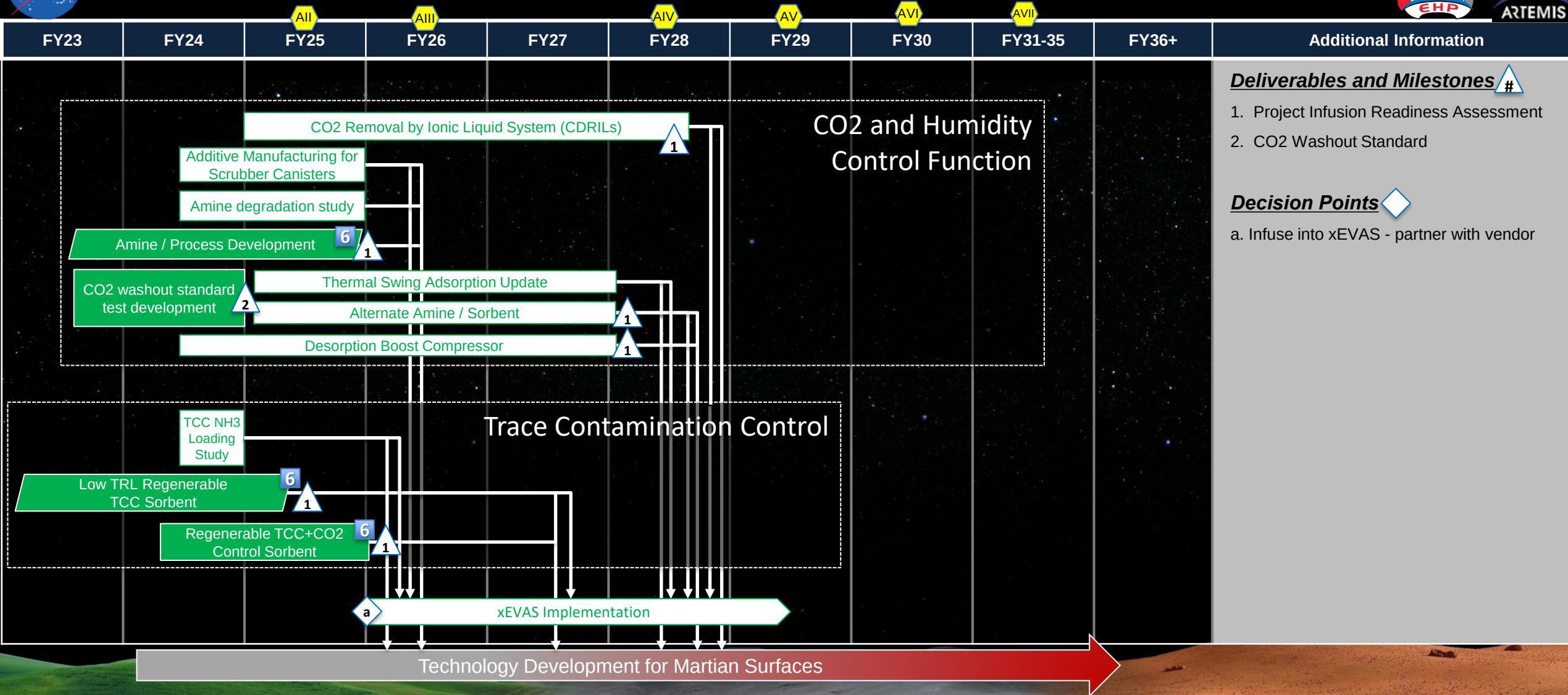


Objectives (FOM/KPPs):

- PLSS System Performance: 8-hour EVA, < 150 lb dry mass, 100 EVA operational life
- Mars System includes operation in a 9 Torr CO2 environment
- Connectors and QD should withstand 1000 cycles in dusty environment
- Sensors must withstand lunar and Martian radiation environments



EVA PLSS: Oxygen Supply and Ventilation (Slide 2 of 2)



Ground

ISS / LEO

Lunar orbit

Lunar surface

Mars transit

Mars surface

Notes

◆ Decision point

▲ Deliverable/Milestone

Act Funded

Act Unfunded

Artemis missions

ESDMD

STMD

Industry

Touchpoint

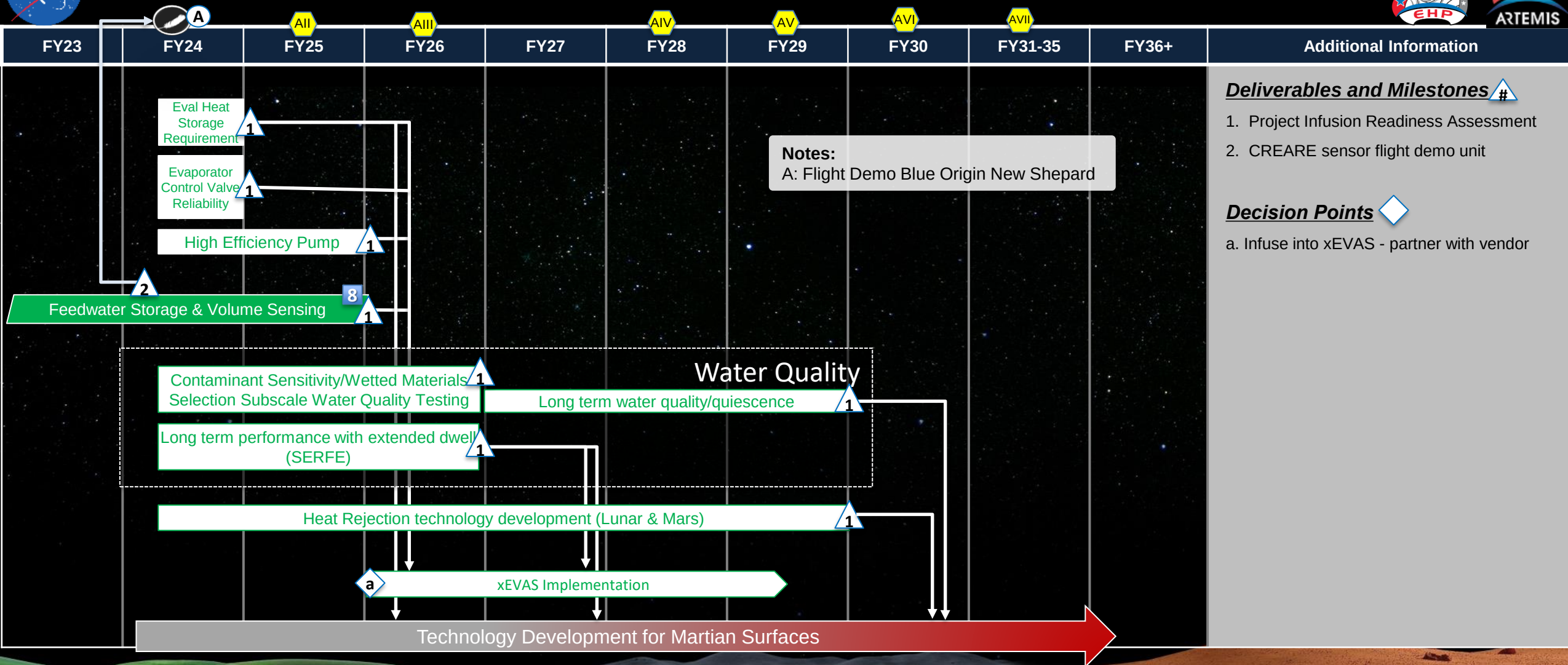
TRL

- Objectives (FOM/KPPs):**
- Actuators should demonstrate 1M cycles, actuation for at extension > 50 lb
 - Gas sensors that can detect multiple gas constituents in addition to CO2 (e. g. NH3, O2, H2O)
 - Regenerable CO2 and humidity control in a 9 Torr CO2 Martian Atmosphere

See acronyms list at front of document. All mission information is notional and for planning purposes only



EVA PLSS: Thermal Control



Deliverables and Milestones

1. Project Infusion Readiness Assessment
2. CREARE sensor flight demo unit

Decision Points

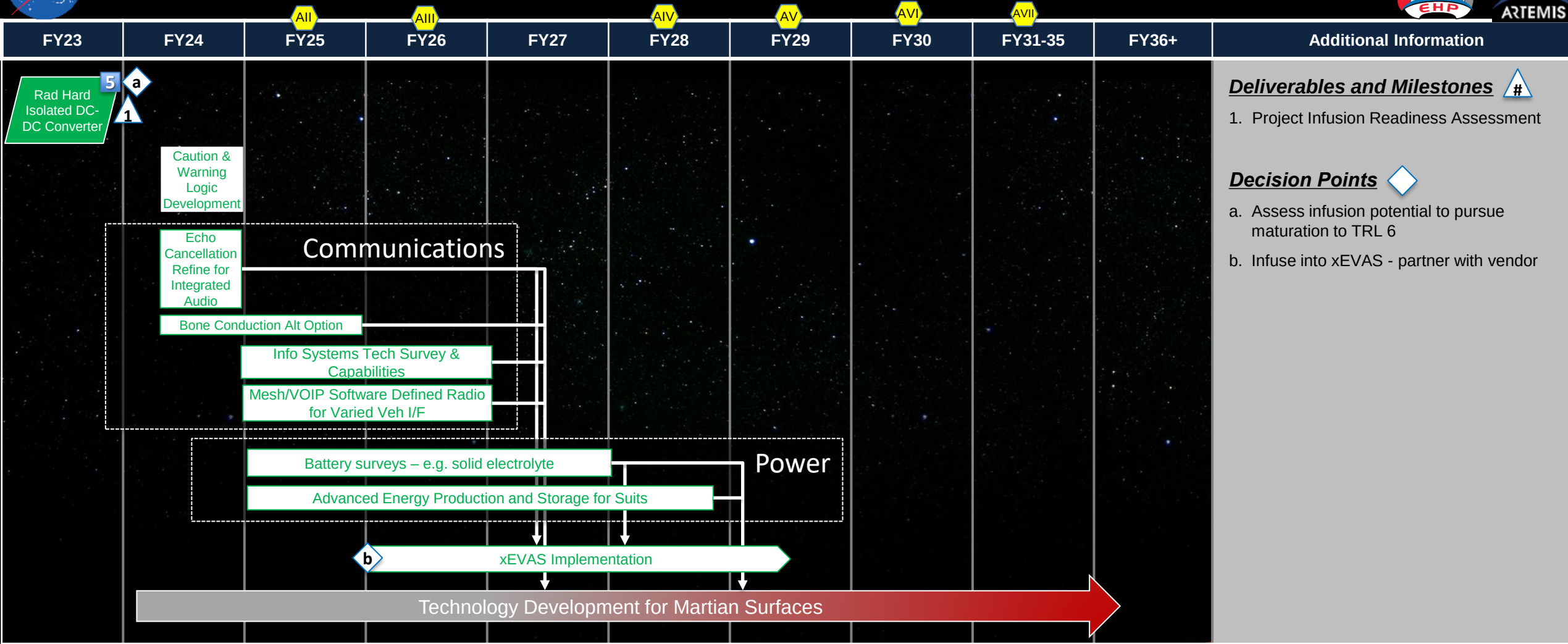
- a. Infuse into xEVAS - partner with vendor

Objectives (FOM/KPPs):

- Heat rejection technologies that operate in the 9 Torr Mars atmosphere
- Low power and mass feedwater supply sensors with an accuracy better than 100 mL
- Water loop operation without maintenance > 800 hours



EVA PLSS: Avionics and Power



Ground

ISS / LEO

Lunar orbit

Lunar surface

Mars transit

Mars surface

Notes

Decision point

Deliverable/Milestone

Funded

Unfunded

Artemis missions

ESDMD

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Touchpoint

TRL

Objectives (FOM/KPPs):

- Integrated audio (off the crew) solutions without feedback and high speech recognition scores
- High energy density suit power supply
- Information systems to provide crew autonomy

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Conclusion

- EVA spacesuits symbolize human space exploration
- Development of a Mars EVA spacesuit is necessary to survive the Martian environment
- Substantial time is needed to develop new technologies
- EVA Spacesuit roadmaps graphically represent the current and notional gap closure activities
- EVA technology development is an iterative process built on lessons learned
- Lunar development efforts began with a schematic study, to bread-board, to initial packaging, to detailed packaging, to xEMU spacesuit government reference design, and now to the xEVAS vendors
- Multiple iterations of new component technologies have resulted in successful infusion from the Advanced EMU to the xEMU and to xEVAS vendors
- EVA Spacesuit roadmaps set the stage for future technology development and will evolve depending on the program's goals and objectives for future missions
- Collaborative investments by industry, academia, and NASA will remain instrumental in advancing EVA technologies

Acknowledgements

- The authors would like to thank and give credit to:
 - Michael Berdich for his support and encouragement in developing the EVA technology roadmaps
 - The engineers that work hard to develop, design, test, and evaluate technology. They embody the CTSD motto

“Pioneering Technology to Live and Work in Space”

EVA Spacesuit Roadmaps Presentation

The background of the slide features a composite image of three astronauts in Extravehicular Activity (EVA) spacesuits. The astronaut on the left is wearing an orange suit. The central astronaut is in a white suit and is holding a camera, capturing a self-portrait. The astronaut on the right is also in a white suit, with a prominent red 'Y' shaped life support system on the chest. The background is a deep space scene filled with numerous bright stars.

This presentation can be located on the NASA Technical Reports Server:

- Link: <https://ntrs.nasa.gov/>
- Choose Publicly Available Content
- Search by title or author



Back-up

What is the EVA PGS?



The Pressure Garment System of a spacesuit provides the following functions:

- Pressure retention
- Enable maximal human mobility
- Provide sufficient physical comfort, thermal comfort and fit
- Provide adequate field of view and gloved interface with the worksite
- Protect against thermal extremes, micro meteoroid orbital debris (MMOD), dust, and worksite hazards

Due to the need to provide these functions, some of which are subjective, while designing for all anthropometries and meeting other requirements such as mass, the PGS becomes a highly integrated system within itself as well as with the human body.

The PGS has key interfaces with other systems in a mission architecture to enable consumables recharge (water, oxygen, and power), communications, power, structural mounting interfaces, vehicles, airlocks, tools, science and logistics payloads, etc.

The PGS will be required to operate farther from Earth, for longer missions, with less opportunities for refurbishment on the ground, and in new environments on the Moon and Mars.

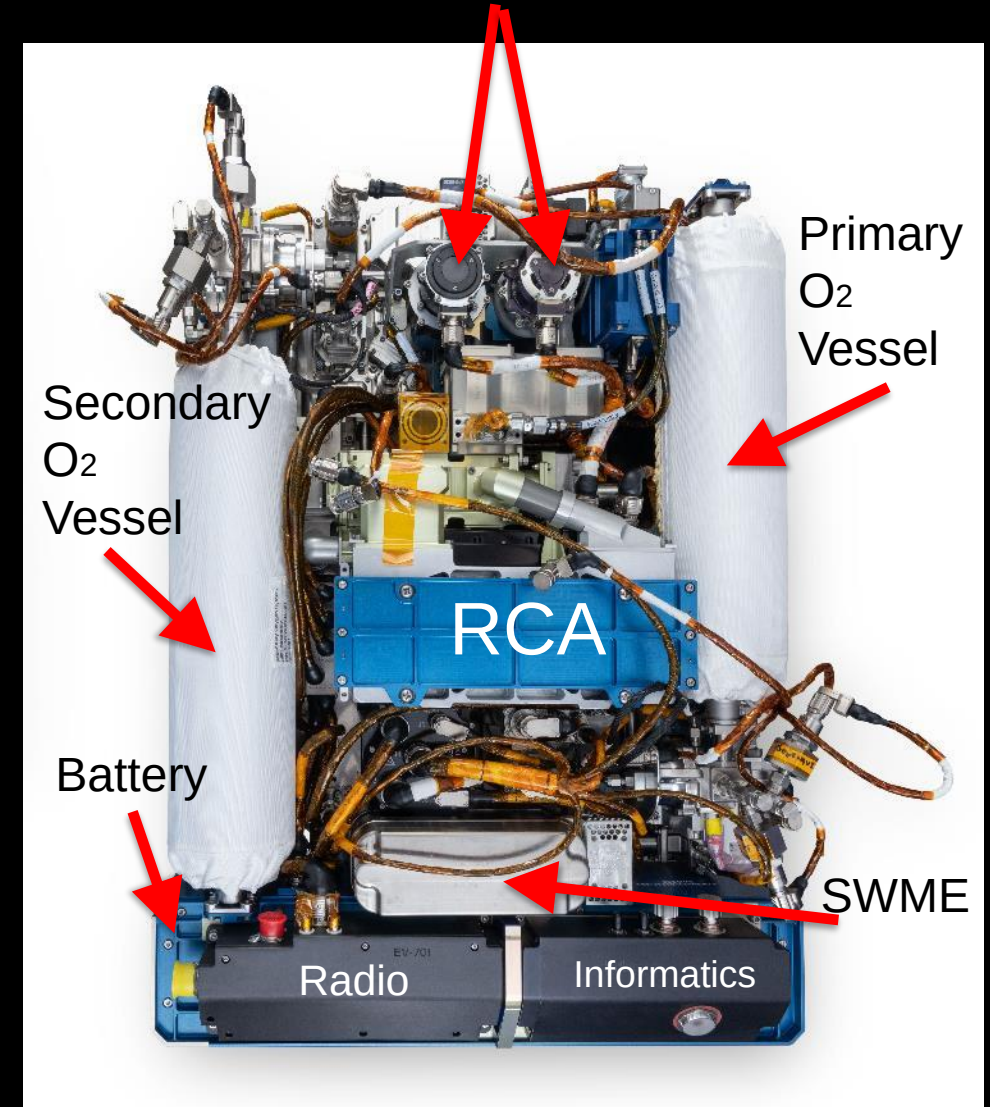
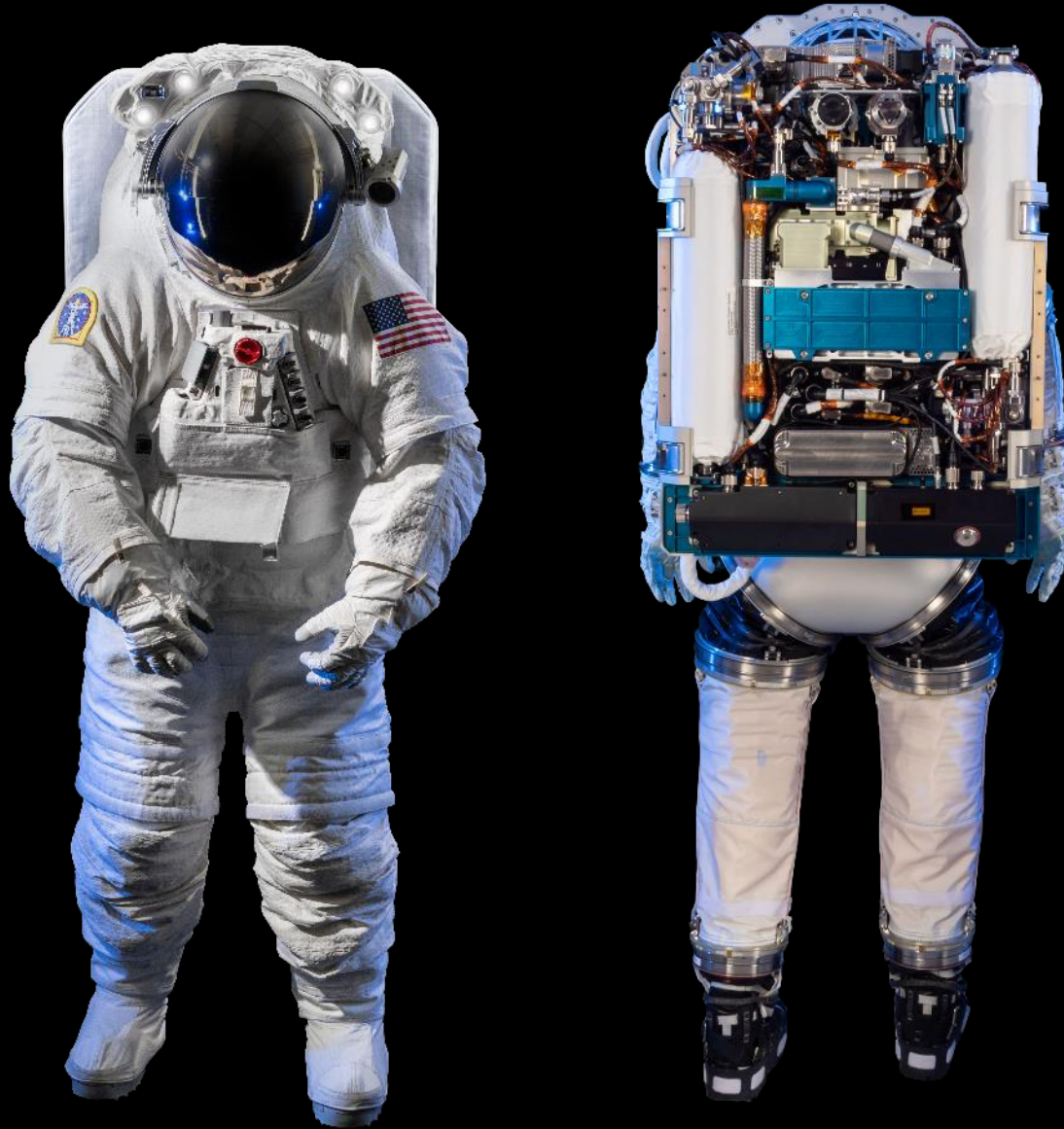


What is the EVA PLSS?



- **The Portable Life Support System of a spacesuit provides the functionality of a single person spacecraft. These functions include:**
 - Oxygen Supply
 - Ventilation
 - Thermal Control
 - Power
 - Command and Data Handling
 - Communications
- **Due to 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.**

What is the EVA PLSS?





ADVANCED PLSS DEVELOPMENT

DEVELOP VERSATILE PLSS THAT CAN OPERATE ACROSS A RANGE OF ENVIRONMENTS IN SUPPORT OF A RANGE OF MISSION AND VEHICLE ARCHITECTURES

COMPLETE

PLSS 1.0
(Breadboard)
2011



- Schematic validation with models
- Component pneumo-hydraulic integration
- Prototype: RCA, Fan, SWME, POR, SOR
- Balance COTS/Instruments
- 8 simulated EVA transient profiles
- 397 hrs of full PLSS operation
- 595 hrs of SWME/thermal loop operation

COMPLETE

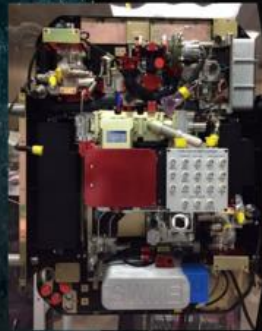
PLSS 2.0
(Packaged GN2)
2012-2015



- Packaged lab unit
- 2nd gen prototypes: POR, SOR, RCA, SWME
- 1st gen prototypes: remainder
- Pre-Installation Acceptance (PIA) test against system spec
- 19 psia air human-in-the-loop testing with the Mark III spacesuit (19 x 2hr EVAs)
- 25 EVAs, failure simulations, integration tests

COMPLETE

PLSS 2.5-301
(Electrical Live Loads)
2015-2017



- Partial build-up to test electrical systems
- Demonstrated power switching between vehicle (SCU) and battery modes; current monitoring and limiting for controllers; DCU commanding to distributed controllers
- Evaluated power quality and electrical noise isolation for controller & CWS signal lines
- Measured electrical noise on analog & digital signal lines, power bus and ground plane of each controller induced by motors/actuators
- Validated PLSS communications protocol

EVOLUTIONARY DESIGN

xPLSS DVT Unit
2018+



- Design Verification Test Unit (Development Unit): flight design without paperwork, path-to-flight avionics
- Requirements verification testing & performance characterization
- Pre-Installation Acceptance (PIA) test against system spec
- Unmanned EVAs in vacuum
- Unmanned thermal vacuum testing at SxEMU level
- DVT PLSS will be maintained as a government asset to evolve the government reference design and support EVA development risk mitigation

FY22+

xEVAS

xEMU GFE approach transitioned to xEVA Services (xEVAS) contract for commercialization of EVA for Artemis & ISS



Adv PLSS Development will continue through:

- xEVAS support and risk mitigation (Insight, Collaboration, GTAs)
- Tech Dev for lower TRL technologies (SBIRs, technology gaps, risk mitigation, Suitport)
- Evolution of the govt reference design



Tips For Reading Roadmaps & Task Bar Key to EVA Spacesuit Roadmaps

Tips for Reading Roadmaps

1 The color of each box represents the activity and the platform where the activity takes place (not the platform where the technology will be enabled). In this example the activity takes place on the ground, although it may be the development of hardware for flight.

2 Each box represents an activity or set of activities, and the length of the box denotes the duration of the activity.

3 CLPS lander icon indicates manifested H/W related to activity.

4 White background indicates activities that are proposed.

5 The shape of each box represents the source of funding. NASA ESDMD, NASA STMD, or Industry. See legend below for shapes.

6 Blue squares indicate Technology Readiness Level (TRL).

7 Boxes that end in an arrow indicate activities without a defined end date, or where the hardware will go into regular operation after a demo.

8 Color codes and icon keys are located in the bottom left corner of each slide.

9 Capability objectives, figures of merit, or key performance parameters are located in the bottom right corner.

FY23	FY24	FY25	FY26
Investment Name		Proposed Activity	
Activity Name			
ABC	Activity Name		

Ground

ISS / LEO

Lunar orbit

Lunar surface

Mars transit

Mars surface

Notes

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Funded

Unfunded

Artemis missions

ESDMD

STMD

Industry

Touchpoint

TRL

Objectives (FOM/KPPs):
Performance measures that define the required capability



NASA Funded “Mars EVA PGS – Enabling” Investments



<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
	None		



Proposed Activities: “Mars EVA PGS – Enabling”



<u>Task Bar Name</u>	<u>Description and Status</u>
Mars 2020 SHERLOC	Complete ground test unit for the Mars 2020 Perseverance Rover Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instrument.
Mars PGS Assessment Study	Mars System Assessment Study to be completed to aid in scope definition of all Mars roadmap tasks.
Mars Thermal Insulation	Multi-layer insulation for low Earth orbit (LEO) and lunar is not an effective thermal insulation on Mars, where conduction dominates. Lightweight, flexible formulation aerogel or similar advanced thermal insulative materials are required. Previous efforts do not meet cycling and thermal requirements.
Mars EPG	Incorporation of Mars-optimized outer materials with Mars thermal insulation into a full environmental protection garment (EPG) assembly which can be evaluated with a PGS for thermal, cycling and mobility performance.
Mars PGS	Incorporate Mars EPG and other Mars investments into a full PGS to evaluate and assess against Mars requirements.
Mars System Reassessment Study	Re-assess Mars PGS after investments into EPG and other enabling technologies are matured and infused into a suit assembly.
Mars Suit System	Mars System Reassessment Study informs Mars Suit System Acquisition Strategy.
Lightweight Material Development	Maturation of lightweight composites or other materials that reduce PGS system mass to enable acceptable performance in Mars gravity.
Additive Manufacturing for PGS components	Additive manufacturing capability for PGS parts would significantly reduce cost for both flight and prototype fabrication. It also enhances EVA system maintainability, improves EVA system sizing schemes, and reduces total EVA system mass for a sustaining architecture by reducing sparing needs.
Materials for Mars Radiation	The long-term performance of suit materials exposed to the Mars radiation environment is unknown. Unique materials for the Mars EPG may be required which involve significant investment.
Planetary Protection	Agency priorities, risk posture and requirements are currently unknown and therefore task is marked TBD. However, it is expected that this area may drive reduced suit leakage and/or compatibility with system-level bio-cleaning procedures.



NASA Funded “Lunar EVA PGS – Sustained Lunar Evolution Enabling” Investments



<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
CO ₂ washout risk assessment	Three-phased approach to update the suited CO ₂ washout methodology following NASA Engineering and Safety Center (NESC) findings/recommendations. Re-assessment and re-design of the suited CO ₂ washout test setup and methodology with joint NASA-external subject-matter expert (SME) team and oversight by Office of the Chief Health and Medical Officer (OCHMO)-led Standing Review Panel. In order to manage the CO ₂ inspired by an astronaut, the spacesuit must scrub the CO ₂ from the life support system, but the flow in the helmet must also carry the exhaled gas away from their oro-nasal region. Helmet is part of the PGS.	2022	2024
Elevated EVA pressure Assessment	Perform an Elevated EVA pressure Assessment to assess mobility impacts on the lunar surface due to elevated EVA pressure. Limited data is available on exploration and decompression sickness (DCS) treatment atmosphere cycle life and mobility performance of PGS components. Assessment of xEMU and other PGS component cycling performance at elevated EVA pressures will inform sustaining mission design maturation and highlight key deficit areas where attention is required to meet current or future requirements.	2024	2024
Glove Risk Mitigation	Lunar Glove Thermal and Durability Analysis, Test, and Failure Mitigation. Develop consistent/standardized testing defined to evaluate durability of existing glove for lunar surface to baseline lunar performance data on the Phase VI gloves from which to compare new design and evaluate material characteristics of candidate lunar EPG materials.	2023	2024
Artemis Suit Material	Develop several EPG material solutions that can be used to mitigate the near-term robustness risks of the xEVAS vendor suit and gloves not being designed for sustained lunar EVAs. This development includes unique evaluation of several concepts to increase material robustness including, but not limited to new materials (fiber, yarn) and fabrication. (weave, finger seams, heater switch)	2023	2027
Scale-Like Structures	Evaluate feasibility of scale-like structures for lunar durability.	2023	2023
Coated Fabrics	Develop and evaluate coated fabrics suitable as EPG outer shell materials.	2023	2024
Helmet Anti-Fog	Multiple vendors are currently working to verify technical feasibility of a durable, effective permanent anti-fog treatment for exploration helmet architectures.	2023	2026
Antimicrobial Bladder	Optimize urethane coatings for anti-microbial performance while not undermining other characteristics of suit bladder materials. Vendor is working with an xEVAS vendor partner and will deliver full EMU arm segments to NASA for future testing.	2023	2024
Electrochromic Visor	Mature an electrochromic visor replacing the manual extravehicular visor assembly (EVVA) shades which carry durability risks and add line in crew field of regard.	2022	2024



Proposed Activities: “Lunar EVA PGS – Sustained Lunar Evolution Enabling”



<u>Task Bar Name</u>	<u>Description and Status</u>
Elevated EVA pressure Mobility Assessment	Perform an Elevated EVA pressure Mobility Assessment Developmental Test Objective (DTO) to assess mobility impacts on the lunar surface due to elevated EVA pressure. Limited data is available on exploration and DCS treatment atmosphere cycle life and mobility performance of PGS components. Assessment of xEMU and other PGS component cycling performance at elevated EVA pressures will inform sustaining mission design maturation and highlight key deficit areas where attention is required to meet current or future requirements.
Knee Pad EPG Eval	Proposal to fly a removable knee pad EPG solution(s) DTO on Artemis III to evaluate candidate sustaining lunar fabrics and wear mitigation solutions.
PGS Charge/Shock Risk Mitigation	Mature characterization of charge/shock risk to EVA and pursue risk mitigation activities.
Comm w/o Snoopy	Intra-helmet audio system that eliminates the need for “snoopy cap” worn inside the helmet.
Glove / Boot Heaters	Develop high efficiency, distributed heat glove and boot heater elements to close thermal gap in lunar permanently shadowed regions (PSRs).
Dust Tolerant Bearings	In partnership with the Dust Mitigation projects development, mature PGS mobility element bearings that are tolerant or more resistant to dust intrusion without impacts to wear or mobility.
Materials for Extreme Thermal Environments	Non-fabric materials for the PGS, such as adhesives, room-temperature vulcanizing materials (RTVs), boot soles, etc.



NASA Funded “EVA PLSS: Cross Subsystem Development and System Architecture” Investments



<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
Mars System Schematic Study	This study will assess potential technologies for a Mars PLSS. Key changes from the xEMU include operation in a low-pressure CO ₂ atmosphere and 1/3 gravity on Mars. The result of this study will be a set of technologies to pursue and a schematic of a Mars PLSS.	2024	2024
Dust Tolerant/Exclusionary Connectors and Quick Disconnects	Connectors are needed (on the suit umbilical as an example) that are dust tolerant or exclusionary. Dust can cause jamming, leakage, or contamination for fluid or electrical connectors.	2022	2024
xEMU Long Term Quiescent Stowage Study	Lunar storage requirements may exceed the originally anticipated requirements, assessments are needed to ensure that materials and system components will still meet requirements after an extended duration of storage at the Gateway or on the lunar surface.	2024	2026



Proposed Activities: “EVA PLSS: Cross Subsystem Development and System Architecture”



<u>Task Bar Name</u>	<u>Description and Status</u>
Low SWaP Rad Hard Pressure Sensors	xEMU pressure sensors use an embedded circuit to amplify the output providing improved precision over existing state of the art. The next step in the evolution of these sensors is to develop a radiation-hardened version.
Lightweight PLSS Structure Packaging Study	This study will assess on-back mass, center of gravity, fall protection, and best overall packaging.
Mars PLSS Proto-type Design and Fab	Mars PLSS Prototype Design and Fabrication: A system level test of the technologies selected in the Mars schematic study will be performed. This will likely be a breadboard style test article to demonstrate basic life support functionality.
Mars Re-assessment System Study	Mars Re-assessment System Study: After this first iteration of the Mars PLSS design, the system and technologies will be re-assessed. This may be an opportunity to incorporate new technologies that have undergone new development since the original Mars PLSS schematic study.
Operations Concepts Maturation	Operations Concepts Maturation: This will be a higher fidelity Mars PLSS. It will include technologies that have been matured through the previous development activities, will address system packaging, can begin to incorporate vehicle interfaces (if available), and can be an asset used to help mature Mars mission studies.
xEMU Integrated Testing Series:	Continued testing of the xEMU government baseline suit reduces risk for the xEVAS vendors
• xEMU System Testing TVAC, Vehicle Interfaces, Fault Logic	• xEMU thermal-vacuum testing completed in FY23. Additional testing with the Short xEMU (SxEMU) can demonstrate additional aspects of the system performance including vehicle interface, fault logic with the Caution and Warning system or lower-level controllers, additional component performance mapping, and increase life cycles on the system.
• Chamber Interface Testing	• The xEMU government suit can be used to demonstrate different test assets that will be available to the xEVAS vendors, such as the 11-foot chamber, Space Station Airlock Test Article (SSATA), or Chamber B.
• Class II Human-rated xEMU Test Unit	• This task would generate an O ₂ -rated xEMU that could be used in sub-sequent human-in-the-loop (HITL) tests.
• Risk Reduction xEVAS HITL Testing	• HITL tests with the xEMU.



NASA Funded “EVA PLSS: Oxygen Supply and Ventilation” Investments



<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
Low TRL Multi-Gas Sensor Development and Testing	The current ISS-EMU and xEMU have CO ₂ sensors to monitor conditions in the suit. Low TRL efforts have previously evaluated multi-constituent sensors that could also potentially measure humidity, oxygen, or ammonia.	2024	2026
O ₂ Flowmeter	Low Pressure Drop Oxygen Flow meter for the PLSS. This is the completion of investment to develop a new concept for a ventilation loop flow meter.	2023	2024
Amine/Process Development	• Nanoporous materials to provide CO₂ and Humidity control for the xEMU with minimal power requirements and low volume and mass. • High-capacity rapid cycle amine (RCA) sorbents for increased cycle times.	2023	2025
CO ₂ washout standard test development	In order to manage the CO ₂ inspired by an astronaut, the spacesuit must scrub the CO ₂ from the life support system, but the flow in the helmet must also carry the exhaled gas away from their oro-nasal region. Quantifying wash out and inspired CO ₂ has historically been difficult. Test results and computational fluid dynamics models are often hard to correlate. An improved, and then standardized methodology is needed to demonstrate acceptable CO ₂ control, especially in this era of commercially provided suits.	2024	2025
Low TRL Regenerable TCC Sorbent	Trace contaminant control (TCC) cartridges are consumables. If a regenerable technology could be developed it would decrease total EVA system mass and in-flight logistics. • Vacuum-Regenerable TCC	2023	2025
Regenerable TCC+CO ₂ Control Sorbent	If a CO ₂ control sorbent could be developed that also captured trace contaminants, this could eliminate a component in the PLSS. • Vacuum-Regenerable Sorbent System • Advanced Multipollutant Trace Contaminant Sorbents	2024	2025



Proposed Activities: “EVA PLSS: Oxygen Supply and Ventilation”



<u>Task Bar Name</u>	<u>Description and Status</u>
Non-jamming Regulator	The xEMU used a common linear actuator to control multiple PLSS components. Actuator jamming was experienced often, making the applicable component inoperable. This task will look at alternative actuator designs for oxygen regulators with the goal of providing reliable operation.
Partial Emission Fan Testing	This task would perform acceptance testing on fans purchased at the end of the xEMU project. This design offer the potential for low power requirements.
Dust Tolerant Relief Valves	Positive and Negative pressure relief valves are included on a suit to prevent over-pressurization from either the inside or outside of the suit (during an airlock repress). These components must be located on the outside of the suit and will be exposed to the dusty environment on the Moon or Mars. Designs are needed that will not experience failures like leakage or sticking after operation in a dusty environment.
CDRILS	Carbon Dioxide Removal by Ionic Liquid System (CDRILS) non-venting, CO ₂ /H ₂ O sequestration. CDRILS will utilize a small hollow-fiber membrane scrubber with a circulating liquid absorbent that would absorb CO ₂ and humidity throughout the EVA and storing it. After the EVA, the ionic liquid will be circulated through the vehicle CDRILS system to recover the CO ₂ /H ₂ O and regenerate the ionic liquid. With modification, the vehicle CDRILS demonstration launching in 2028 could integrate the Mars EMU CDRILS and allow for demonstration of the technology for both applications.
Low Press Drop and Leak Check Valves	The xEMU added redundant, parallel, fans to the system design. This drove a new requirement for a check valve to prevent back-flow through the non-operating unit. Initial xEMU check valve designs did not meet pressure drop or leakage requirements, which put additional burden on the fans to provide the required flow through the helmet of the suit.
Additive Manufacturing for Scrubber Canisters	Multiple alternate CO ₂ and Humidity control development efforts are needed to address key risks and push these technologies forward. These include assessing additive manufacturing techniques to build the scrubber canisters, evaluating how the current state of the art sorbent (SA9T) degrades over time, and developing new sorbents. These can be short term technologies, like assessing the Thermal Swing Adsorption technology under test in the 4BedCO ₂ payload on ISS for EVA application, that are applicable to sustained lunar missions or for Mars missions. Martian missions provide a new technical challenge because regenerable technologies must reject CO ₂ into the CO ₂ atmosphere on Mars. Mars technologies could be different sorbents, different regeneration methods, or potentially a boost compressor on the scrubber regeneration line to drive CO ₂ into the higher partial pressure environment.
Amine degradation study	
Alternate Amine / Sorbent	
Thermal Swing Adsorption Update	
Desorption Boost Compressor	
TCC NH ₃ Loading Study	The SA9T sorbent currently used as the state-of-the-art CO ₂ control technology produces small amounts of ammonia when it reacts with water. This becomes a driving constituent in the sizing of a TCC cartridge. Additional evaluations of this generation rate could reduce the size or increase the duration of use for a TCC cartridge.



NASA Funded “EVA PLSS: Thermal Control” Investments

<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
Feedwater Storage and Volume Sensing	Water is one of the primary consumables for a life support system that uses evaporation for cooling. A reliable, and gravity independent, technique for measuring the amount of water remaining is critical to monitoring the duration of an EVA. Volume Sensor for Flexible Fluid Reservoirs in Microgravity. Flight Demo on New Shepard, December 18, 2023 launch.	2018	2024
	High-Purity, Defined-Envelope pressure Bladder.	2022	2024



Proposed Activities: “EVA PLSS: Thermal Control”



<u>Task Bar Name</u>	<u>Description and Status</u>
Evaluate Heat Storage Requirement	Crew members generate variable amounts of heat during an EVA based on their activity levels. There are requirements for energy storage in the crew (as monitored by core body temperature) if their metabolic output exceeds the cooling capability of the life support system. Refinement of this requirement could enable sizing reductions for thermal control hardware.
Evaporator Control Valve Reliability	The xEMU Suit Water Membrane Evaporator (SWME) uses a backpressure control valve to meter the water evaporation rate and thereby the cooling provided to the crew. The xEMU design experienced many issues with linear actuator reliability where the motor would jam, making the control valve inoperable. This task would look at designs that provide more reliable actuation while still meeting the flow rate and pressure drop requirements.
High Efficiency Pump	Continued development and evaluations of water pumps with lower power requirements is desired.
Contaminant Sensitivity / Wetted Materials Selection Subscale Water Quality Testing	Water quality issues have plagued the ISS-EMU and other life support systems throughout NASA's history. xEMU-based technology development efforts for SWME and the SWME Express Rack Flight Experiment (SERFE) ISS payload have taken large steps to demonstrate decreased sensitivity to water quality issues and improved materials compatibility as compared to previous systems. However, continued efforts are needed to completely reduce risks associated with water quality. These include sub-scale tests to assess materials or contaminants that might present performance issues to the current thermal control technologies; long term quiescent evaluations with the SERFE Ground Unit where it is tested after long dormant periods (> 2 years), and then additional long-term evaluations as the xEVAS designs are finalized and mission concepts mature.
Long term water quality / quiescence	
Long term performance with extended dwell (SERFE)	
Heat Rejection technology development (Lunar and Mars)	The low-pressure CO ₂ environment on Mars may degrade the performance of water evaporation-based technologies. In addition, non-venting heat rejection or storage technologies could decrease mission consumables. Low TRL heat rejection technologies need to be continually evaluated for potential benefits.



NASA Funded “EVA PLSS: Avionics and Power” Investments

<u>Task Bar Name</u>	<u>Description and Status</u>	<u>Start</u>	<u>Finish</u>
Radiation Hardened Isolated DC-DC Converter	Self-calibrating, lightweight radiation hardened isolated Direct Current to Direct Current (DC-DC) converter. Radiation hardened electronic components typically lag in performance as compared to consumer electronics. This SBIR developed a radiation hardened DC-DC convertor to distribute power inside of a PLSS controller.	2020	2023



Proposed Activities: “EVA PLSS: Avionics and Power”



<u>Task Bar Name</u>	<u>Description and Status</u>
Caution and Warning Logic Development	This task can be performed as part of continued xEMU system level testing. xEMU testing has generally demonstrated life support functionality. Additional, evaluations can further develop and demonstrate the government baseline avionics and software design, especially in the areas of off-nominal operations or failure conditions.
Echo Cancellation Refinement for Integrated Audio	The xEMU has significant risk with audio quality based on the design of integrating the microphones and speakers directly into the upper torso of the suit and not using a communications cap. This is especially critical once two suits are joined into the same loop. Risk reduction activities range from improved echo cancellation algorithms to improved acoustics inside of the helmet to speaker and microphone selection and placement.
Bone Conduction Microphone	An alternative to current microphones could be an earpiece style microphone that converts vibrations in the user’s head into communication signals.
Information Systems	The xEMU only developed the most basic information systems, including video and data streaming. Additional applications and hardware could range from heads up or wrist displays, to navigational tools, to electronic checklists. This is an area where continued development could enhance EVA efficiency and crew autonomy.
Mesh / Voice over Internet Protocol Software Defined Radio	The ISS-EMU and xEMU still rely on a radio frequency-based radio infra-structure. Future lunar networks are still being defined. A software defined radio with an internet protocol-based communication scheme is more representative of the current commercial state of the art in communication technologies.
Battery Survey	Commercial battery applications drive technology at a much faster rate than the space industry. Continued assessment of emerging technologies for spacesuit applications can provide improvements in energy density, which translates to longer EVAs and less massive batteries.
Advanced Energy Production and Storage for Suits	Spacesuits have always relied on batteries for power. Other technologies, potentially solar, thermal, fuel cells, or motion-based energy production should periodically be assessed and traded.



Acronyms



AEMU	Advanced EMU		HITL	Human in the Loop		RTV	Room-Temperature Vulcanizing
CLPS	Commercial Lunar Payload Services		HLR	Human Lunar Return		SBIR	Small Business Innovative Research
CMW	Change Management Workflow		HLS	Human Landing System		SCU	Service and Cooling Umbilical
CO2	Carbon Dioxide		ISS	International Space Station		SERFE	Suit Water Membrane Evaporator (SWME) Express Rack Flight Experiment
COTS	Commercial Off The Shelf		JSC	Johnson Space Center		SHERLOC	Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals
CWS	Caution and Warning System		KPP	Key Performance Parameter		SLE	Sustained Lunar Evolution
DC-DC	Direct Current to Direct Current		KSC	Kennedy Space Center		SMD	Science Mission Directorate
DCU	Display and Control Unit		LEO	Low Earth Orbit		SOR	Secondary Oxygen Regulator
DT	DT mailcode		LL	Lessons Learned		SSATA	Space Station Airlock Test Article
DTO	Developmental Test Objective		M2M	Moon to Mars Program		STMD	Space Technology Mission Directorate
E	ESDMD		MCO	Mars Campaign Office		STTR	Small Business Technology Transfer
EEE	Electrical, Electronic, and Electromechanical		MMOD	Micro Meteoroid Orbital Debris		SWaP	Size Weight and Power
EHP	EVA and Human Surface Mobility Program		M-PALS	Multi-Parameter Astronaut Life Support Sensor		SWME	Suit Water Membrane Evaporator
EMU	EVA Mobility Unit		NESC	NASA Engineering and Safety Center		SxEMU	Short xEMU, Short Exploration EMU
EPG	Environmental Protection Garment		O2	Oxygen		TBD	To Be Determined
ESDMD	Exploration Systems Development Mission Directorate		OCHMO	Office of the Chief Health and Medical Officer		TCC	Trace Contaminant Control
EVA	Extravehicular Activity		OPR	Office of Primary Responsibility		TP	Tipping Point
FOM	Figures of Merit		PGS	Pressure Garment System		TRL	Technology Readiness Level
FY	Fiscal Year		PIA	Pre-Installation Acceptance		TVAC	Thermal Vacuum
GCD	Game Changing Development		PLSS	Portable Life Support System		VOIP	Voice of Internet Protocol
GFE	Government Furnished Equipment		POR	Primary Oxygen Regulator		xEMU	Exploration EVA Mobility Unit
GN2	Gaseous Nitrogen		PSR	Permanently Shadowed Regions		xEVA	Exploration EVA
GTA	Government Task Agreement		R&D	Research and Development		xEVAS	Exploration EVA Services contract
			RCA	Rapid Cycle Amine			

