



# FY26 Civil Space Shortfall Prioritization

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# Introduction

NASA's Space Technology Mission Directorate (STMD) leads the development, demonstration, and infusion of transformational technologies that enhance NASA's efforts to explore the unknown in space, benefit life on Earth, and solve critical stakeholder needs.

STMD's investment strategy informs its portfolio to:

**ADVANCE** technologies beyond the cutting edge to accomplish NASA's most ambitious missions

**ACCELERATE** a vibrant and competitive space economy by fueling breakthrough ideas and strategically embracing risk

**FOSTER** collaboration with a robust U.S. aerospace community to ensure American leadership

In spring 2024, STMD kicked off a new collaborative process to better integrate the community's most pervasive technical challenges and guide NASA's space technology investments. STMD published a document overviewing 187 shortfalls – technology areas requiring further development to meet future exploration, science, and other mission needs – and asked the aerospace community to rate their importance. In July, STMD released the 2024 Civil Space Shortfall Ranking document, integrating the input received from NASA mission directorates and centers, small and large industry organizations, other government agencies, academia, and other interested individuals. STMD uses the integrated ranked list as one of many inputs into decision-making.

The 2026 effort builds on NASA's previous shortfall ranking experience and leverages the feedback provided by stakeholders to streamline the process by consolidating the shortfalls (SF) into 32 broader, integrated categories. A shortfall is defined as a technology area requiring further development to meet future exploration, science, and other mission needs. The term "gap" is widely used across NASA and the aerospace industry and implies that both ends of the problem – the current state of the art and the technology needed – are known. In the case of shortfalls, the knowledge of the current state may be all that exists. Each shortfall includes a subset of specific need statements (NS) to provide further definition and context and better guide specific areas for technology investment to address the shortfall. *A table describing the Shortfalls and Need Statements can be found in Appendix A.* This restructuring maintains the original content's depth while creating a more efficient and accessible feedback mechanism for participants.

This document presents the results of stakeholder feedback in the form of Shortfall rankings, and a high-level overview of how the feedback was collected and analyzed.

# Data Collection

Shortfall prioritization inputs were collected from three sources, NASA Mission Directorates, NASA Centers, and the space community at large. Responses from NASA were coordinated internally with one consolidated response from Exploration Systems Development Mission Directorate (ESDMD), Science Mission Directorate (SMD), each of the Centers and the Jet Propulsion Laboratory (JPL). Responses from the space community at large were collected via a public call for feedback, where stakeholders external to NASA were asked to rank their top 15 shortfalls in order of priority and provide comment.

## NASA Mission Directorate Rankings

The Mission Directorate rankings were done at the need statement level. Need statements were designed to align 1-to-1 with needs identified by various stakeholders. The architecture-driven technology gaps, identified in the most recent Moon to Mars Architecture Definition Document (ADD), represent 72 of the need statements and were identified by ESDMD. Similarly, needs identified by SMD are reflected by 19 need statements. In both cases, ESDMD and SMD ranked their identified needs.

## NASA Center Rankings

Each NASA Center and the Jet Propulsion Lab identified the top 25 need statements that aligned with their priorities, workforce and competencies, in priority order.

# Space Community Rankings

From the public call for feedback NASA received 454 total external responses. Each response was considered the input of a single individual, not a consolidated response of the organization they represented. Respondents provided their self-identified stakeholder group from within the following categories: Industry, Academia, Other Government Agency (OGA), or Other. The Other category predominantly included non-profits, Federally Funded Research and Development Centers (FFRDCs), unaffiliated members of the general public and NASA employees responding as individuals. Additionally, a smaller number of individuals associated with non-space related industries such as law firms, finance and the media were included in the Other category. The graph below shows the detailed breakdown of the responses from each group.



Figure 1: External feedback responses

## Data Analysis

The Mission Directorate input served as the initial source for scoring the civil space shortfalls in order of priority. Their rankings at the Need Statement level were rolled up into scores at the Shortfall level. The scores of SMD and ESDMD were aggregated to create an aggregate score for each Shortfall. Center inputs and the feedback received from the public via the feedback solicitation were utilized to identify the Shortfalls that were identified as high priority across multiple stakeholder groups. Where there was wide interest, an overlap bonus i.e. and additional weighting, was applied to the aggregate Mission Directorate score to account for these common priorities. The final scores were then ordered 1-32 to represent the whole community's Shortfall priority ranking.

# FINAL SHORTFALL RANKINGS



# Shortfall Rankings

The table below provides the final ranking 1-32 for the Shortfalls after the analysis of stakeholder inputs was performed. These rankings are purely derived from the quantitative feedback provided from the queried stakeholders and include no qualitative judgement or commentary on the timeline on which each shortfall needs to be addressed to meet agency objectives.

SFID	Description	Final 1-32 Rank
SF02	Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.	1
SF16	Provide surface mobility and logistics for crew and assets on planetary surfaces.	2
SF25	Provide on-board advanced computing capabilities for space operations.	3
SF11	Land science payloads on planetary surfaces.	4
SF06	Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment.	5
SF23	Transport and maneuver uncrewed spacecraft for missions in cislunar and deep space.	6
SF13	Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.	7
SF24	Provide tracking and navigation of crew and assets in space.	8
SF28	Autonomously monitor, inspect, maintain, and repair space assets.	9
SF15	Operate multi-agent robotic and crewed systems in cooperative planetary surface activities.	10
SF26	Collect and return preserved science samples and other products to Earth facilities.	11
SF09	Safely, reliably, and precisely land large systems on the Martian surface.	12
SF12	Transport crew and cargo from Earth to the Moon and Mars and back.	13
SF32	Develop an affordable and resilient supply chain for space exploration.	14

<b>SFID</b>	<b>Description</b>	<b>Final 1-32 Rank</b>
SF03	Safely, routinely, and precisely land large systems on the lunar surface.	15
SF04	Deploy, assemble, and construct complex structures on the lunar surface.	16
SF20	Provide adequate food, water, and supplies to ensure crew mental and physical wellbeing during long duration missions.	17
SF19	Provide efficient, outfitted habitation capable of long duration missions.	18
SF05	Produce propellant, consumables, and other usable materials from lunar resources to support human exploration and commercial activities.	19
SF21	Provide Earth-independent safety and crew health and performance countermeasures during long duration missions.	20
SF01	Perform safe, Earth-independent Extravehicular Activities on the lunar surface.	21
SF27	Emplace and maintain large, stable space platforms and observatories.	22
SF14	Perform missions with small spacecraft beyond low Earth orbit.	23
SF08	Perform safe, Earth-independent Extravehicular Activities on the Martian surface.	24
SF18	Efficiently and responsibly manage waste streams during long duration missions.	25
SF07	Provide communication solutions to assets and crew during missions to Mars.	26
SF30	Reduce likelihood and consequence of impacts with in-space objects.	27
SF10	Produce propellant, consumables, and other usable materials from Martian resources to support human exploration.	28
SF31	Provide space technology demonstration environments.	29
SF29	Protect Earth from destructive impacts from naturally occurring objects near Earth.	30
SF22	Provide a ground support infrastructure capable of supporting a launch cadence sufficient for continuous lunar access and missions to Mars.	31
SF17	Provide robotic access to subsurface and atmospheric regimes.	32

# STMD TOP 40 FOCUS AREAS



# STMD Top 40 Focus Areas

After completing the data analysis, STMD accounted for several qualitative factors, such as NASA's "Ignition" event which occurred after stakeholder data collection, to inform focus areas for STMD investments. As part of its Ignition event, NASA announced a series of transformative agencywide initiatives designed to achieve the President's National Space Policy and advance American leadership in space. In addition to alignment with Ignition, STMD also factored in agency science needs, technology developments focus areas for other agency organizations, maintaining robust technical expertise within STMD, preserving support of critical skill at centers, establishing paths for collaboration with industry, ensuring relevance with academia, and leveraging overlaps in interests with OGAs.

After ranking the Shortfalls, taking the above factors into consideration, and examining STMD's portfolio of capabilities, the following 40 Need Statements were selected as the primary focus areas for STMD in FY26. Investments will address the challenges shown below with the greatest depth and breadth that funding allows. This list represents the primary focus areas at a snapshot in time and are subject to change as information and directions shift. All investment decisions are based on many factors, and this list is not meant to exclude any content but rather represents the primary areas for focused investments.

Need ID	Description
3.02	Land on lunar south pole exploration sites in various illumination conditions with appropriate accuracy. Reference ESDMD #1101 (landing accuracy) for specific details.
23.06	Provide magnetically shielded, human-rated electric propulsion.
2.02	Provide low power, thermal management, and actuation for distributed surface assets to survive and operate in the lunar environment. Reference ESDMD #0301 (mobile assets) for specific details.
15.01	Provide scalable, reliable surface-to-surface communications between assets on the lunar surface that is usable by all participating elements. Reference ESDMD #0103 (Moon) for specific details.
2.07	Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (lunar) for specific details.
4.01	Perform site preparation and bulk regolith manipulation for infrastructure construction, including landing pads, berms, regolith overburden for radiation protection. Reference ESDMD #0605 (manipulation) for specific details.
3.01	Predict plume surface interaction (PSI) surface erosion, crater width/depth, and ejecta energy flux during landing. Reference ESDMD #1101 (PSI characterization) for specific details.
4.03	Autonomously assemble and construct structures on the lunar surface. Reference ESDMD #0504 for specific details.
11.01	Develop and validate performance models for entry systems.

Need ID	Description
16.05	Transfer low-loss cryogenic fluid between spacecraft in partial gravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (surface) for specific details.
16.04	Efficiently store propellant for appropriate durations in partial gravity environments while minimizing boil-off. Reference ESDMD #1106 (surface) for specific details.
3.03	Perform stable touchdown and operation of large vehicles on uneven, sloped, and undulating lunar surfaces.
24.03	Provide autonomous orbit determination, navigation, and pointing of operating spacecraft in deep space.
16.08	Transfer pressurized gases between exploration assets on planetary surfaces.
12.04	Transfer Earth-storable propellant and pressurized gases between exploration assets in space. Reference ESDMD #0503 (in-space) for specific details.
16.02	Offload, handle, and manipulate payloads from elevated heights on planetary surfaces. Reference ESDMD #0806 for specific details.
12.06	Robotically assemble modular flight elements for large transportation systems.
23.01	Access atmospheric planetary bodies with resiliency to launch date using aerocapture.
13.01	Increase sensitivity and resolution of science instruments by orders of magnitude with quantum technologies.
4.04	Construct structures on the lunar surface through advanced manufacturing techniques. Reference ESDMD #0505 for specific details.
13.02	Increase sensitivity and performance of photon detectors.
13.09	Provide advanced networking needed for multi-spacecraft responsive space operations.
25.02	Develop space-based computing technology needed for autonomous on-board operations.
19.02	Provide mass-efficient habitat structures capable of supporting mission relevant crew size and duration. Reference ESDMD #0306 for specific details.
5.02	Excavate and transport lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0605 (excavation and transportation) for specific details.
14.04	Provide reliable transportation for small spacecraft to destinations beyond cislunar space.
24.04	Extend U.S. space situational awareness capabilities to cislunar space.
24.05	Develop a lunar position, navigation, and timing architecture capable of scaling to long term operational needs.

Need ID	Description
32.03	Provide high-efficiency power conversion using alternative radioisotopes to maximize the effectiveness of existing plutonium sources.
27.01	Provide precise attitude control for ultra-stable observatories.
23.05	Provide in-space diagnostics for electric propulsion.
23.02	Provide low-cost science observations from orbits requiring continuous propulsive activity.
2.06	Provide extreme cold-tolerant robotic and mobility capabilities to enable use cases for surveying and accessing permanently shadowed regions for sample retrieval. Reference ESDMD #0804 for specific details.
13.08	Autonomously perform science operations on commercial LEO destinations and lunar surface laboratories.
12.03	Efficiently store propellant for appropriate durations in microgravity environments while minimizing boil-off. Reference ESDMD #1106 (in-space) for specific details.
12.05	Transfer low-loss cryogenic fluid between spacecraft in microgravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (in-space) for specific details.
9.03	Decelerate large payloads to the Martian surface. Reference ESDMD #1103 (entry and descent) for specific details.
5.04	Produce oxygen from lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0601 for specific details.
28.01	Implement space-based manufacturing techniques for in-situ repairs and replacement of hardware components. Reference ESDMD #0502 for specific details.
26.04	Store and process cryogenically cold samples for return to Earth. Reference ESDMD #1201 (cryo) for specific details.

# CONCLUSION



# Conclusion

This document presented the approach to collecting data, top level feedback received, and the high-level methodology for prioritizing among the 32 civil space shortfalls. It also provided insight into STMD's priorities for aligning support with technology developments across the agency. It represents the priorities of the community from a snapshot in time. As agency objectives, architectures, and missions evolve these priorities are expected to evolve with them. STMD intends to assess and update the shortfalls, need statements and their associated priorities on a three-year cadence to inform their investment strategy, however, major shifts in agency objectives and guidance will be incorporated as required. For more information on past and present information on the shortfalls please visit the Civil Space Shortfalls website. Future updates will be posted at this location.

## Shortfall and Need Statement Descriptions

Shortfall	Need ID	Need Statement
<b>1.0 Perform safe, Earth-independent Extravehicular Activities on the lunar surface.</b>	1.01	Provide lunar spacesuits compatible with lunar surface gravity, dust, thermal environment, and atmosphere, capable of mission relevant EVA duration, dwell time, frequency, and use life.
	1.02	Provide lunar spacesuit physiology capable of supporting long duration lunar mission EVA strategy with acceptable risk of adverse outcomes. Reference ESDMD #0406 (Moon) for specific details.
	1.03	Provide lunar spacesuits with variable and adjustable sizing to fit the astronaut population.
	1.04	Provide crew ingress/egress capabilities that protect the crew, habitat, and suits.
	1.05	Provide crew mobility for traverses on lunar surface.
	1.06	Provide in-situ decision support tools to address identified EVA hazards and risks on the lunar surface.
<b>2.0 Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.</b>	2.01	Provide high power, thermal management, and actuation for surface assets to survive and operate in the lunar environment. Reference ESDMD #0301 (fixed assets) for specific details.

Shortfall	Need ID	Need Statement
<p><b>2.0 Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.</b></p>	2.02	Provide low power, thermal management, and actuation for distributed surface assets to survive and operate in the lunar environment. Reference ESDMD #0301 (mobile assets) for specific details.
	2.03	Provide scalable, multi-kWe-scale power generation and storage capable of supporting crew safety and exploration activities in lunar temperatures, dust, and solar availability conditions. Reference ESDMD #0901 for specific details.
	2.04	Provide robust and low-mass power management and distribution solutions for long-duration operations in extreme environments. Reference ESDMD #0903 (Lunar) for specific details.
	2.05	Operate surface assets efficiently for required durations, preventing extreme wear and tear to systems or mechanisms from lunar dust and regolith. Reference ESDMD #0801 for specific details.
	2.06	Provide extreme cold-tolerant robotic and mobility capabilities to enable use cases for surveying and accessing permanently shadowed regions for sample retrieval. Reference ESDMD #0804 for specific details.
	2.07	Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (lunar) for specific details.
	2.08	Provide electrical charge dissipation sufficient to ensure hardware and crew safety.
	2.09	Mitigate and survive high velocity impacts of small particles on lunar surface assets.
<p><b>3.0 Safely, routinely, and precisely land large systems on the lunar surface.</b></p>	3.01	Predict plume surface interaction (PSI) surface erosion, crater width/depth, and ejecta energy flux during landing. Reference ESDMD #1101 (PSI characterization) for specific details.
	3.02	Land on lunar south pole exploration sites in various illumination conditions with appropriate accuracy. Reference ESDMD #1101 (landing accuracy) for specific details.
	3.03	Perform stable touchdown and operation of large vehicles on uneven, sloped, and undulating lunar surfaces.
	3.04	Provide surface support infrastructure to routinely land on and ascend from the lunar surface.

Shortfall	Need ID	Need Statement
<b>4.0 Deploy, assemble, and construct complex structures on the lunar surface.</b>	4.01	Perform site preparation and bulk regolith manipulation for infrastructure construction, including landing pads, berms, regolith overburden for radiation protection. Reference ESDMD #0605 (manipulation) for specific details.
	4.02	Deploy load-bearing structures on the lunar surface.
	4.03	Autonomously assemble and construct structures on the lunar surface. Reference ESDMD #0504 for specific details.
	4.04	Construct structures on the lunar surface through advanced manufacturing techniques. Reference ESDMD #0505 for specific details.
<b>5.0 Produce propellant, consumables, and other usable materials from lunar resources to support human exploration and commercial activities.</b>	5.01	Locate, characterize, and map the useful resources on the lunar surface.
	5.02	Excavate and transport lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0605 (excavation and transportation) for specific details.
	5.03	Extract metal and manufacturing feedstock from lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0604 for specific details.
	5.04	Produce oxygen from lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0601 for specific details.
	5.05	Produce water from icy lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0603 for specific details.
	5.06	Produce power components derived from in-situ resources.
	5.07	Excavate and transport lunar regolith at a scale relevant for sustained lunar exploration.
	5.08	Produce metals, oxygen, and water at a scale relevant for sustained lunar exploration.
	5.09	Manage, store, and distribute in-situ-produced materials and products at a scale relevant to sustained lunar exploration.
	5.10	Manage conversion, storage, and handling of oxygen into breathing air sufficient to support sustained lunar exploration mission needs.

Shortfall	Need ID	Need Statement
<b>6.0 Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment.</b>	6.01	Provide robust and low-mass power management and distribution solutions for long-duration operations in extreme environments. Reference ESDMD #0903 (Mars) for specific details.
	6.02	Operate surface assets efficiently for long durations, preventing extreme wear and tear to systems or mechanisms from Martian dust and regolith. Reference ESDMD #0802 for specific details.
	6.03	Mitigate and survive high velocity impacts of small particles on Martian surface assets.
	6.04	Provide scalable, multi-kWe-scale power generation and storage capable of supporting assets and crew safety in Martian temperatures, dust, and solar availability conditions. Reference ESDMD #0902 for specific details.
	6.05	Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (Mars) for specific details.
<b>7.0 Provide communication solutions to assets and crew during missions to Mars.</b>	7.01	Provide reliable uplink and downlink solutions that prevent or mitigate data disruptions between Earth and Mars. Reference ESDMD #0102 (data reliability) for specific details.
	7.02	Transfer data at sufficient rates to supply high-definition streaming and still imagery between Earth and Mars. Reference ESDMD #0102 (data rate) for specific details.
	7.03	Transfer data at sufficient rates to accommodate science operations at Mars.
<b>8.0 Perform safe, Earth-independent Extravehicular Activities on the Martian surface.</b>	8.01	Provide Martian spacesuits compatible with Mars surface gravity, dust, thermal environment, and atmosphere, capable of mission relevant EVA duration, dwell time, frequency, and use life. Reference ESDMD #0803 for specific details.
	8.02	Provide Martian spacesuit physiology capable of supporting Mars mission EVA strategy with acceptable risk of adverse outcomes. Reference ESDMD #0406 (Mars) for specific details.
	8.03	Provide Martian spacesuits with variable and adjustable sizing to fit the astronaut population.
	8.04	Provide ingress and egress between surface habitat, other surface elements, and the Martian surface.

Shortfall	Need ID	Need Statement
<b>8.0 Perform safe, Earth-independent Extravehicular Activities on the Martian surface.</b>	8.05	Provide appropriate water purity, oxygen, and power needed for Martian spacesuits.
	8.06	Provide in-situ decision support tools to address identified EVA hazards and risks on the Martian surface.
	8.07	Provide crew mobility for long traverses on Martian surface.
<b>9.0 Safely, reliably, and precisely land large systems on the Martian surface.</b>	9.01	Characterize and predict plume surface interaction (PSI) surface erosion, crater width/depth, and ejecta energy flux, and mitigate effects of PSI ejecta on Martian surface assets. Reference ESDMD #1102 (PSI Characterization) for specific details.
	9.02	Predict Mars entry mission performance before flight with validated entry models. Reference ESDMD #1103 (modeling) for specific details.
	9.03	Decelerate large payloads to the Martian surface. Reference ESDMD #1103 (entry and descent) for specific details.
	9.04	Land large payloads within an intended target range on Mars while detecting and avoiding obstacles. Reference ESDMD #1102 (landing accuracy) for specific details.
	9.05	Perform stable touchdown and operation of large vehicles on uneven, sloped, and undulating Martian surfaces.
<b>10.0 Produce propellant, consumables, and other usable materials from Martian resources to support human exploration.</b>	10.01	Locate, characterize, and map the useful resources on the Martian surface.
	10.02	Excavate/accumulate, manipulate, and transport Martian resources at mission relevant scale.
	10.03	Produce consumables, propellant, and other usable materials at mission relevant scale to support human Mars missions. Reference ESDMD #0606 for specific details.
	10.04	Manage, store, and distribute propellants, consumables, and other usable materials sufficient for mission needs on Mars.
<b>11.0 Land science payloads on planetary surfaces.</b>	11.01	Develop and validate performance models for entry systems.
	11.02	Develop low cost, high performance entry systems.
	11.03	Develop new atmospheric entry systems to reduce risk and mass requirements for precision landing.
	11.04	Land science payloads on sites in various illumination conditions.
	11.05	Perform stable touchdown, deployment, and operation of science payloads on uneven, sloped, and undulating surfaces.

Shortfall	Need ID	Need Statement
<b>12.0 Transport crew and cargo from Earth to the Moon and Mars and back.</b>	12.01	Transport crew and cargo from near Earth to near Mars and return crew safely back to near Earth. Reference ESDMD #1104 for specific details.
	12.02	Integrate propellant resources across systems to maximize resource efficiency in transit.
	12.03	Efficiently store propellant for appropriate durations in microgravity environments while minimizing boil-off. Reference ESDMD #1106 (in-space) for specific details.
	12.04	Transfer Earth-storable propellant and pressurized gases between exploration assets in space. Reference ESDMD #0503 (in-space) for specific details.
	12.05	Transfer low-loss cryogenic fluid between spacecraft in microgravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (in-space) for specific details.
	12.06	Robotically assemble modular flight elements for large transportation systems.
	12.07	Ascend with crew and cargo from the surface of Mars to Mars-orbit. Reference ESDMD #1105 for specific details.
	12.08	Reliably and safely land crew and cargo return vehicles at designated landing sites on Earth.
<b>13.0 Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.</b>	13.01	Increase sensitivity and resolution of science instruments by orders of magnitude with quantum technologies.
	13.02	Increase sensitivity and performance of photon detectors.
	13.03	Provide high-performance imagery for remote sensing across the energy spectrum.
	13.04	Study and discover highly energetic phenomena in the universe.
	13.05	Provide a cosmic-dust-penetrating view into the early universe.
	13.06	Detect biosignatures at exoplanets.
	13.07	Deliver non-imaging science measurement capabilities for particle and field sensors needed in distributed spacecraft systems conducting multi-point solar observations.
	13.08	Autonomously perform science operations on commercial LEO destinations and lunar surface laboratories.
	13.09	Provide advanced networking needed for multi-spacecraft responsive space operations.

Shortfall	Need ID	Need Statement
<b>13.0 Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.</b>	13.10	Provide a holistic, efficient, and effective wildland fire crisis management system.
<b>14.0 Perform missions with small spacecraft beyond low Earth orbit.</b>	14.01	Miniaturize sensors and instrumentation on small spacecraft.
	14.02	Increase power generation and storage systems for small spacecraft.
	14.03	Efficiently reject heat in small spacecraft.
	14.04	Provide reliable transportation for small spacecraft to destinations beyond cislunar space.
	14.05	Perform entry, descent, and/or landing for small spacecraft efficiently and cost effectively.
<b>15.0 Operate multi-agent robotic and crewed systems in cooperative planetary surface activities.</b>	15.01	Provide scalable, reliable surface-to-surface communications between assets on the lunar surface that is usable by all participating elements. Reference ESDMD #0103 (Moon) for specific details.
	15.02	Provide dust-tolerant docking and berthing systems and utility connections that enable transfer of crew, cargo, and commodities between modules for cooperative surface operations. Reference ESDMD #0807 for specific details.
	15.03	Achieve safe, efficient human-robot interactions for exploration missions, secure command and control over high-latency, bandwidth-limited networks, or implement reliable automated safing sequences. Reference ESDMD #1005 for specific details.
	15.04	Perform Earth-independent cooperative tasks on planetary bodies using autonomous software tools in multi-agent robotic systems.
<b>16.0 Provide surface mobility and logistics for crew and assets on planetary surfaces.</b>	16.01	Autonomously maneuver and navigate to achieve faster mobility with an order of magnitude greater range. Reference ESDMD #0805 for specific details.
	16.02	Offload, handle, and manipulate payloads from elevated heights on planetary surfaces. Reference ESDMD #0806 for specific details.
	16.03	Relocate large assets on planetary surfaces. Reference ESDMD #0808 for specific details.

Shortfall	Need ID	Need Statement
<b>16.0 Provide surface mobility and logistics for crew and assets on planetary surfaces.</b>	16.04	Efficiently store propellant for appropriate durations in partial gravity environments while minimizing boil-off. Reference ESDMD #1106 (surface) for specific details.
	16.05	Transfer low-loss cryogenic fluid between spacecraft in partial gravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (surface) for specific details.
	16.06	Store Earth-storable fluids in extreme thermal environments.
	16.07	Transfer Earth-storable propellant between exploration assets on planetary surfaces. Reference ESDMD #0503 (surface) for specific details.
	16.08	Transfer pressurized gases between exploration assets on planetary surfaces.
	16.09	Minimize crew manual labor through efficient tools to enable fluid transfer on a planetary surface.
<b>17.0 Provide robotic access to subsurface and atmospheric regimes.</b>	17.01	Autonomously perform deep drilling operations in sub-surface regions beyond current capability for pristine/unmodified materials.
	17.02	Provide autonomous mobility in subsurface applications (solid, granular, and fluid).
	17.03	Provide aerial mobility on Mars.
	17.04	Provide aerial mobility on Venus.
	17.05	Provide aerial mobility on Titan.
<b>18.0 Efficiently and responsibly manage waste streams during long duration missions.</b>	18.01	Manage logistics and waste streams to maximize reuse, minimize logistics footprint and waste, and prevent microbial and volatile releases that contaminate the vehicle and planetary surfaces. Reference ESDMD #0702 for specific details.
	18.02	Identify, quantify, and mitigate contamination at exploration destinations with minimal crew effort and operational complexity. Reference ESDMD #1202 for specific details.
	18.03	Recycle metabolic waste in-situ.
	18.04	Utilize recycled material as feedstock in space-based manufacturing.
	18.05	Manage the thermal energy waste stream.

Shortfall	Need ID	Need Statement
<b>19.0 Provide efficient, outfitted habitation capable of long duration missions.</b>	19.01	Monitor atmospheric quality, microbes, airborne particles, trace contaminants, and acoustics to prevent health/operational issues and guide off-nominal responses, without Earth sample return and with minimal consumables and crew time. Reference ESDMD #0304 (atmosphere) for specific details.
	19.02	Provide mass-efficient habitat structures capable of supporting mission relevant crew size and duration. Reference ESDMD #0306 for specific details.
	19.03	Manage the thermal environment of habitation systems for long duration missions.
	19.04	Provide Earth-independent planning, scheduling, and troubleshooting capabilities for long duration missions.
	19.05	Provide audio and visual crew interfaces for long duration missions.
<b>20.0 Provide adequate food, water, and supplies to ensure crew mental and physical wellbeing during long duration missions.</b>	20.01	Provide potable water systems with safe and effective long-term maintenance and recovery that meet the chemical and microbial potable water requirements during long duration missions. Reference ESDMD #0303 for specific details.
	20.02	Monitor water quality, microbes, and trace contaminants to prevent health/operational issues and guide off-nominal responses without Earth sample return and with minimal consumables and crew time. Reference ESDMD #0304 (water) for specific details.
	20.03	Deliver food, supplements, and supplies in low-mass, interoperable containers—both conditioned and unconditioned—that are human-robotic compatible, transportable, thermally stable, recyclable/reusable, and maintainable for year+ missions. Reference ESDMD #0701 for specific details.
	20.04	Provide a variety of food systems that are safe and palatable during long duration missions, contain nutritional shelf life, and can withstand the environment within the habitat. Reference ESDMD #0305 (food storage) for specific details.
	20.05	Grow crops for long-duration missions. Reference ESDMD #0305 (food production) for specific details.

Shortfall	Need ID	Need Statement
<b>21.0 Provide Earth-independent safety and crew health and performance countermeasures during long duration missions.</b>	21.01	Increase crew safety from fire hazards in low and partial gravity environments at reduced pressures and increased oxygen levels. Reference ESDMD #0302 for specific details.
	21.02	Monitor and forecast space and planetary weather sufficient to ensure safety of crew and assets for mission relevant durations. Reference ESDMD #0307 for specific details.
	21.03	Reduce adverse crew health outcomes due to radiation exposure via mass-efficient, mission compatible countermeasures in alignment with NASA-STD-3001 V1 4030 & 4031. Reference ESDMD #0308 for specific details.
	21.04	Accurately monitor and maintain physical health and performance during long duration missions. Reference ESDMD #0401 for specific details.
	21.05	Meet crew health and performance standards for sensorimotor health during long duration missions. Reference ESDMD #0402 for specific details.
	21.06	Reduce adverse crew physical health and performance outcomes via mission-compatible countermeasures under communication delay and without resupply. Reference ESDMD #0403 for specific details.
	21.07	Prevent or address anticipated mental health needs experienced during exploration missions via Earth-Independent mental and behavioral health countermeasures. Reference ESDMD #0404 for specific details.
	21.08	Provide Earth-Independent health and medical care capabilities sufficient to address anticipated medical needs experienced during exploration. Reference ESDMD #0405 for specific details.
	21.09	Operate crewed missions without Earth-based instruction during safety critical operations that require immediate response.

Shortfall	Need ID	Need Statement
<b>22.0 Provide a ground support infrastructure capable of supporting a launch cadence sufficient for continuous lunar access and missions to Mars.</b>	22.01	Provide efficient public safety measures for the increase cadence of launches and return configurations.
	22.02	Provide space nuclear systems infrastructure support and launch readiness.
	22.03	Provide vehicle and payload processing facilities sufficient for lunar and Mars missions.
	22.04	Provide fueling facilities sufficient to support lunar and Mars missions.
<b>23.0 Transport and maneuver uncrewed spacecraft for missions in cislunar and deep space.</b>	23.01	Access atmospheric planetary bodies with resiliency to launch date using aerocapture.
	23.02	Provide low-cost science observations from orbits requiring continuous propulsive activity.
	23.03	Transfer storable propellant between science, communication, or other satellites in near-Earth space.
	23.04	Develop novel power and propulsion technologies for rapid and efficient in-space transportation across the solar system.
	23.05	Provide in-space diagnostics for electric propulsion.
	23.06	Provide magnetically shielded, human-rated electric propulsion.
	23.07	Transfer electric propulsion propellant between assets in space.
<b>24.0 Provide tracking and navigation of crew and assets in space.</b>	24.01	Achieve absolute localization of crew, mobile, and other surface assets in the lunar surface environment. Reference ESDMD #0101 for specific details.
	24.02	Provide high-availability, Earth-independent tracking of position, navigation, and timing targeting continued coverage despite disruptions and/or blackout periods, for deep space surface missions. Reference ESDMD #0104 for specific details.
	24.03	Provide autonomous orbit determination, navigation, and pointing of operating spacecraft in deep space.
	24.04	Extend U.S. space situational awareness capabilities to cislunar space.
	24.05	Develop a lunar position, navigation, and timing architecture capable of scaling to long term operational needs.

Shortfall	Need ID	Need Statement
<b>25.0 Provide on-board advanced computing capabilities for space operations.</b>	25.01	Provide radiation-tolerant onboard computing operations to support autonomy, navigation, and other high-performance use cases in relevant environments. Reference ESDMD #0202 for specific details.
	25.02	Develop space-based computing technology needed for autonomous on-board operations.
	25.03	Distribute Avionics & Sensors systems and functions within spacecraft or surface systems.
	25.04	Provide advanced computing needed for multi-spacecraft responsive space operations.
<b>26.0 Collect and return preserved science samples and other products to Earth facilities.</b>	26.01	Collect, manipulate, and verify samples and products from planetary bodies, while preserving sample integrity.
	26.02	Identify and classify samples of scientific interest on planetary bodies.
	26.03	Store and process conditioned samples for return to Earth. Reference ESDMD #1201 (conditioned) for specific details.
	26.04	Store and process cryogenically cold samples for return to Earth. Reference ESDMD #1201 (cryo) for specific details.
	26.05	Return conditioned samples/products to Earth.
	26.06	Transport preserved samples from Earth lander to Earth laboratory, while preserving sample integrity.
<b>27.0 Emplace and maintain large, stable space platforms and observatories.</b>	27.01	Provide precise attitude control for ultra-stable observatories.
	27.02	Reduce spacecraft exposure to vibration to enable high precision pointing accuracy.
	27.03	Achieve required structural accuracy and stability for space structures of varying magnitudes and precision requirements.
	27.04	Robotically upgrade large space observatory instruments and avionics.
	27.05	Create and evolve systems beyond current launch size limitations.

Shortfall	Need ID	Need Statement
<b>28.0 Autonomously monitor, inspect, maintain, and repair space assets.</b>	28.01	Implement space-based manufacturing techniques for in-situ repairs and replacement of hardware components. Reference ESDMD #0502 for specific details.
	28.02	Provide robotic systems capable of inspection, maintenance, and repair operations that function autonomously and as part of a human-robot team. Reference ESDMD #0501 for specific details.
	28.03	Provide environmentally robust robotic, imaging, and sensing components with sufficient performance for challenging exploration missions. Reference ESDMD #1001 for specific details.
	28.04	Autonomously monitor systems and crew that support human exploration including during Mars-distance communication delays and blackouts. Reference ESDMD #1002 for specific details.
	28.05	Autonomously detect and diagnose off-nominal conditions and events; safe, reliable, autonomous control of systems; and automated control and safing sequences. Reference ESDMD #1003 for specific details.
	28.06	Provide software platforms that can analyze data and make decisions autonomously while providing explainable reasoning or inspection capabilities necessary to establish trust. Reference ESDMD #1004 for specific details.
<b>29.0 Protect Earth from destructive impacts from naturally occurring objects near Earth.</b>	29.01	Detect, track, and characterize Near Earth Objects.
	29.02	Model, predict, and integrate data on Near Earth Objects.
	29.03	Deflect and disrupt collision paths.
<b>30.0 Reduce likelihood and consequence of impacts with in-space objects.</b>	30.01	Characterize small debris in LEO and cis-lunar space.
	30.02	Protect payloads in high micrometeoroid flux locations from micrometeoroid impacts.
	30.03	Detect, attribute, and characterize orbital debris strikes and effects upon spacecraft on orbit.
	30.04	Autonomously generate feasible close approach mitigation and maneuver instructions consistent with the physics-based and operational constraints of spacecraft and operators.
	30.05	Remediate large debris in space.

Shortfall	Need ID	Need Statement
<b>31.0 Provide space technology demonstration environments.</b>	31.01	Provide surface-based platforms for technology demonstrations.
	31.02	Provide environmental simulators, test facilities, and test sites for technology development in relevant environments.
	31.03	Provide a platform for astronauts to develop skills and maintain proficiency operating in microgravity.
	31.04	Provide on-orbit platforms and interfaces for technology and operations demonstrations.
	31.05	Access higher altitude and longer duration flights for suborbital and orbital vehicles and high-altitude balloons.
	31.06	Provide accommodations and opportunities on launch vehicles or for re-entry and return capabilities.
<b>32.0 Develop an affordable and resilient supply chain for space exploration.</b>	32.01	Manufacture low-cost, mass-efficient, large flight components.
	32.02	Provide readily available, low size, weight, power, and cost (SWaP-C) high bandwidth deep-space-compatible communication systems.
	32.03	Provide high-efficiency power conversion using alternative radioisotopes to maximize the effectiveness of existing plutonium sources.
	32.04	Ensure a sufficient number of domestic suppliers can provide space qualified systems within required lead times.

For more information on the ESDMD technology gaps referenced in the need statements please see the [Moon to Mars website](#).

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