National Aeronautics and Space Administration

NASA'S MOON TO MARS STRATEGY AND OBJECTIVES DEVELOPMENT

A blueprint for sustained human presence and exploration throughout the Solar System

FOREWORD

In the 21st century, space is the place – for innovation and for discovery. It is a place to invent, create, and reflect on humanity's place in the universe.

When we first began our journey to extend the reach of human achievement, we were in a space race to demonstrate that our Nation had the ingenuity to be first to land humans on the Moon.

With that feat accomplished, a new generation, inspired by the Apollo missions, pursued scientific and technological advancements to the great benefit of our Nation. We spent the intervening decades doing things never done before, like creating a reusable space vehicle and constructing an orbiting outpost where humans conduct science and research for long periods of time in microgravity.

We are now at a historical pivot point in space. Our space industry has proven its ability to do things that once were the sole province of governments, and it is now extending our space economy from low-Earth orbit to cislunar space. Our global partners also seek to explore the Moon, and thus we will return together, through international and public-private partnerships. And then it's on to Mars.

We return to a Moon about which we know so much more than we did a half century ago – but to a different and more challenging location. It's a Moon where science has shown us craters in permanent shadow that might have water. Where there is water, there is rocket fuel – hydrogen and oxygen that can propel us to farther destinations, creating opportunities for research and innovation that are seemingly endless.

We return to the Moon to stay. To learn and to live and to create. To do incredible science we can do nowhere else. To continue to build our Nation's capabilities in space, creating positive effects on our economy, our security, and our daily lives. And we go to inspire the Artemis Generation to extend human presence and exploration throughout the solar system – and beyond.

This great endeavor requires a strategy that is technically and financially resilient and that reflects a unity and constancy of purpose across the Agency. Our strategy will reflect our Nation's leadership and values in science and exploration and harness our ability to inspire. We will go together with our international partners and industry enablers.

This strategy was developed to return to the Moon in a steady cadence of increasingly difficult missions, ultimately enabling our goal to send humans to Mars and beyond. The best minds at NASA collaboratively determined areas to focus our efforts, informed by feedback from the NASA workforce, international partners, industry, and the public. Throughout this campaign, we will continue to incorporate input from all our stakeholders as we explore new frontiers and once again do things that humanity has never done before.

Today, we are creating a future where spacefaring nations peacefully explore the secrets of the universe for the benefit of all. Our enduring blueprint for sustained human presence and exploration throughout the solar system builds on the Artemis missions and the capabilities of tomorrow. The golden age of exploration is happening right now, and this strategy will guide our efforts as we reach farther into the cosmos.

Bill Nelson

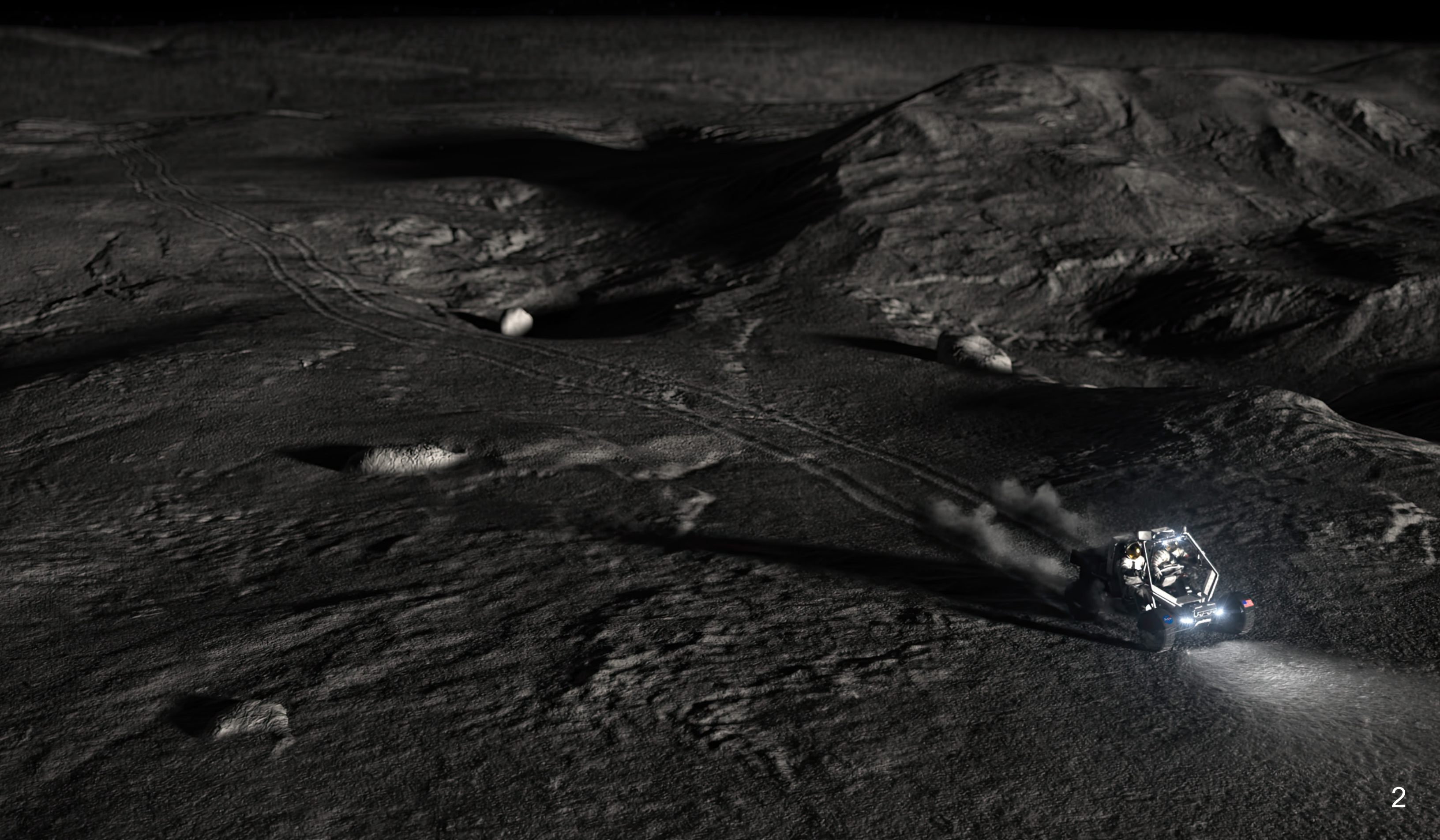
Bill Nelson
Administrator
NASA

EXECUTIVE SUMMARY

Documented here are NASA's Moon to Mars strategy and top-level goals and objectives, designed to achieve the vision to create a blueprint for sustained human presence and exploration throughout the solar system. The vision – bold and complex – must be broken down via systems engineering application to ensure strategic progress toward success. Systems engineering begins with understanding the motivation for the effort, the opportunities and risks to the process, and a discussion of recent history that has influenced the current state. Through systems engineering, the vision is broken into attainable pieces, starting with an initial endeavor, goals and objectives associated with that endeavor, and the additional pieces necessary to achieve the goals and objectives. Five methodology principles combine with the robust systems engineering process to guide implementation toward the blueprint vision and in so doing, improve resilience for the Moon to Mars endeavor.

The Moon to Mars goals and objectives are the centerpiece of this document, which serve as a guidepost for the years-long endeavor. Development of the objectives spanned one year, and involved gap analysis and cross-assessment within NASA, a robust feedback campaign with the public, industry, academia, and international partners, and a vetting process to revise the goals and objectives. Recurring tenets came out of the vetting process, along with rationale for the goals.

The strategy is not static; it requires ongoing review and feedback to continue to evolve based on new minds, new technology, and new developments. Annual iterative reviews form the strategic next steps, with the goal of implementing change with detail, rigor, and consistency such that the vision, goals, and objectives are not altered, but improved.



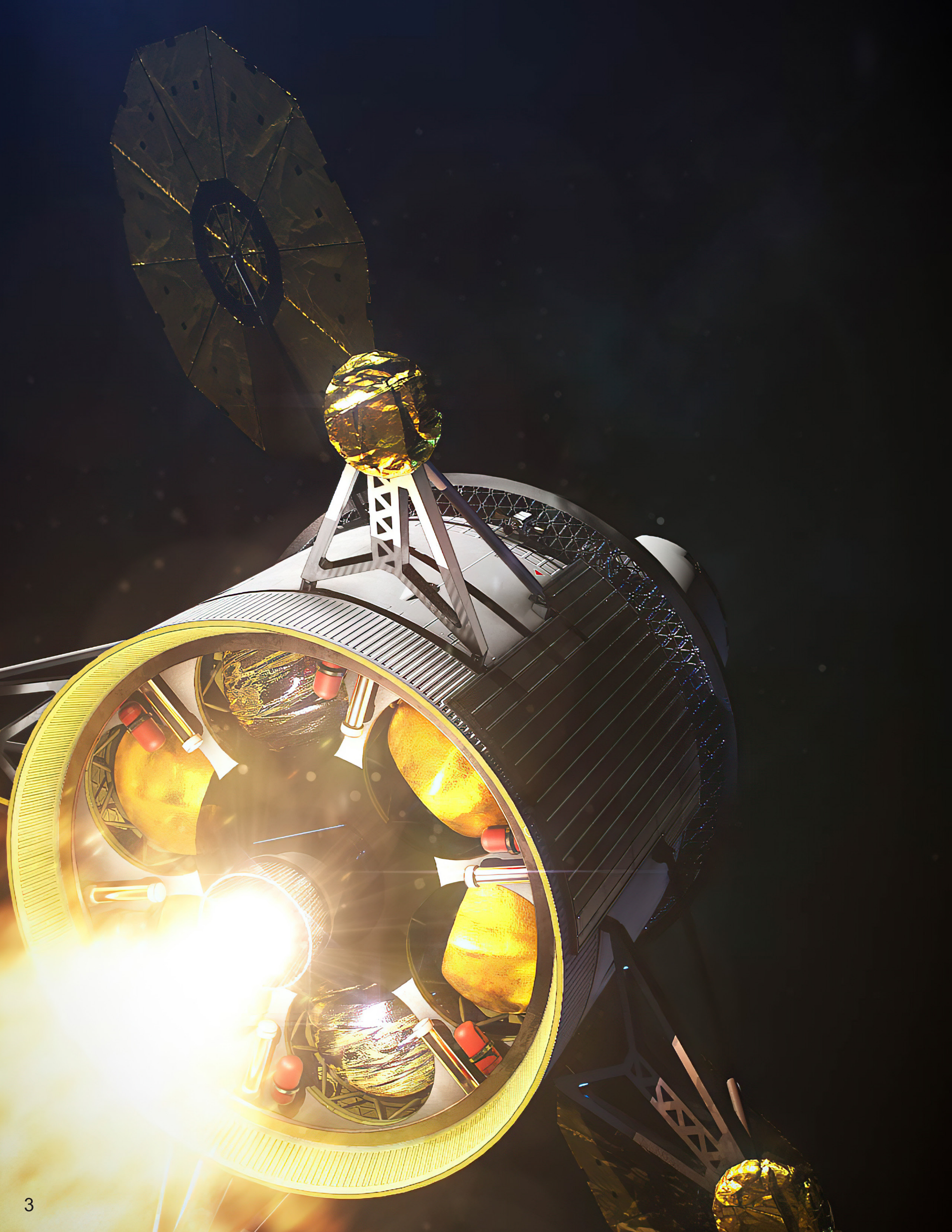


TABLE OF CONTENTS

1.0 INTRODUCTION

As history shows, successful human spaceflight missions are a result of herculean systems engineering efforts. Efforts such as these lay the groundwork for the future, where technical engineering excellence rises to the challenge in an integrated way to surmount the perceived insurmountable.

> *"Apollo was much more a management exercise than anything else, and that the technological challenge, while sophisticated and impressive, was largely within grasp at the time of the 1961 decision. More difficult was ensuring that those technological skills were properly managed and used," then NASA Administrator James E. Webb contended.*

In the new era, alignment is paramount, because human space exploration is not NASA's alone. Successful missions are and will be the culmination of years of dedicated and consistent effort by NASA, the industrial base, and international partner space agencies – a direct result of teamwork and consistent support of external stakeholders. This new era heralds a lofty **vision**: "Create a blueprint for sustained human presence and exploration throughout the solar system." To begin to achieve that vision, NASA is working toward the near-term Moon to Mars **endeavor**, with resulting **goals** and **objectives** to guide success. An excellent **systems engineering process** is the **strategy** by which the endeavor will be achieved, and, alongside teamwork and partnerships, will enable resilience in human spaceflight over time and across budget cycles and administrations. Together, these strategic components will feed toward achieving the overarching blueprint vision to reach destinations beyond the Moon and Mars.

NASA's Moon to Mars strategy and the development process used to define the overarching Moon to Mars objectives are documented herein.

In so doing, the strategy establishes a **wireframe** – an architectural structure that connects space exploration projects, programs, and NASA mission directorates in a meaningful way toward achievable goals. The wireframe helps achieve the near-term endeavor while enabling the long-term vision. Coupled with that architectural process is an ongoing feedback mechanism to bring partners and workforce along in the journey. While the strategy to achieve the vision withstands time and external influences, the architectural approach can and must incorporate outside feedback to connect today's developments with the achievements of tomorrow.

The purpose of this document is to outline NASA's Moon to Mars strategy as well as the development process used to define the overarching Moon to Mars objectives. This framework will drive NASA's architecture, plans, and efforts in enabling sustained human presence and exploration throughout the solar system.

Moon to Mars Strategy Definitions

Architecture: A set of functional capabilities, their translation into elements, their interrelations, and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

Endeavor: A near-term, aspirational accomplishment that serves as the guidepost both for progress toward a long-term vision as well as for success in strategically architected goals, objectives, and activities that advance progress toward the accomplishment.

Goal: Target set by an organization to achieve its vision. Goals are broader than objectives, but shorter-term than an endeavor or vision.

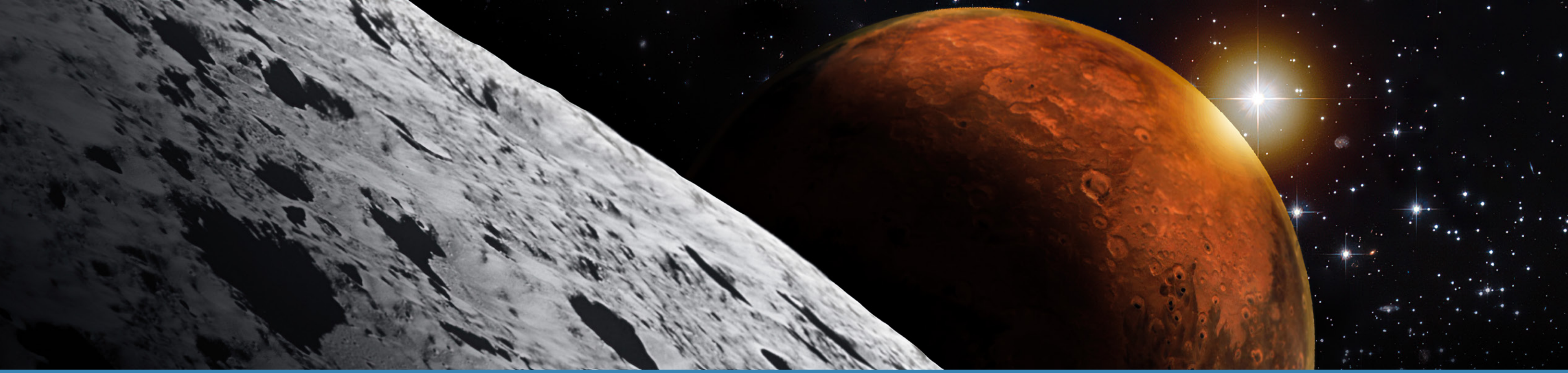
Objective: Statement that defines a goal more specifically and helps achieve desired outcomes.

Systems Engineering: Interdisciplinary approach to designing, integrating, and managing complex systems over their life cycles to combine synergistic components that collectively reach a desired future state.

Strategy: Set of guiding principles designed to achieve a major aim or desired vision.

Vision: An imaginative, aspirational future state toward which an organization strives.

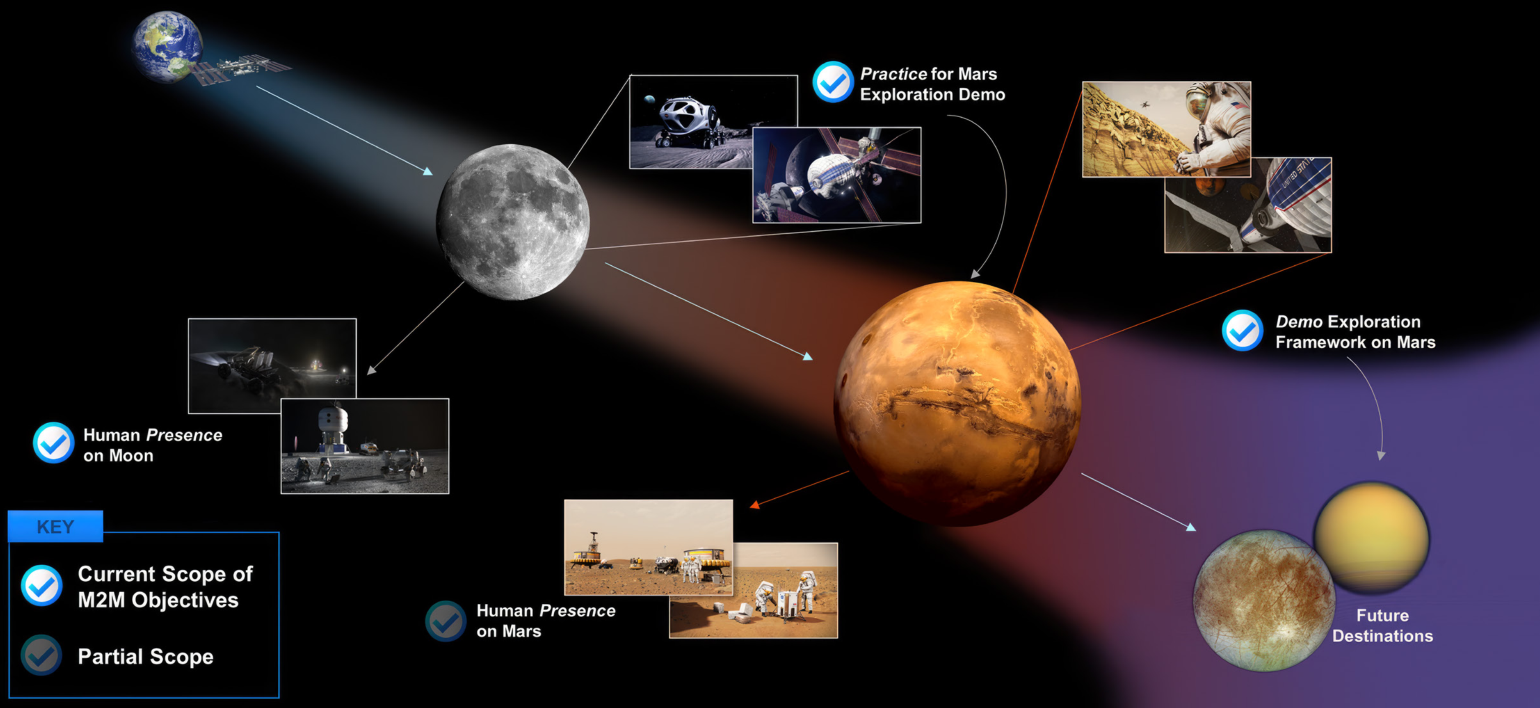
Wireframe: An architectural structure that connects projects, programs, and entities in a meaningful way toward achievable goals, with purpose toward the near-term endeavor and long-term vision. Wireframe can be used interchangeably with Architecture.



1.1 Scope

The scope used for the development of the strategy and top-level goals and objectives assumed neither a weighted focus on returning to the Moon nor moving swiftly on to Mars. Instead, the Moon to Mars endeavor embraces the need to do both. With an eye toward future exploration, the strategy allows for humanity to learn to adapt, live, thrive, navigate, produce, and prosper in each new domain – which then prepares for the next. From the dawn of time, this has been humanity's exploration tactic. As an example: low-Earth orbit. First, humanity arrived, then thrived, then learned to live and produce, and a robust low-Earth orbit commercial economy blossomed soon after.

CURRENT MOON TO MARS SCOPE



Identified goals and objectives are designed to first achieve the Moon to Mars endeavor, which will strategically position space exploration to extend beyond these destinations, reaching farther into the solar system to achieve the blueprint vision.

The same will be true in the Moon to Mars endeavor. The Moon is a proving ground to develop and demonstrate capabilities that will lay the foundation for humans to thrive, while at the same time offering opportunities to learn and prepare for an initial Mars campaign. The arrival at Mars will offer the same duality to extend humanity's reach farther into the solar system.

2.0 BACKGROUND AND CONTEXT

NASA's Moon to Mars strategy is conducted by following an optimal systems engineering process, the first step of which is to ask, *Why Go?* Other key factors shaping the new approach include the historical context of space exploration efforts and NASA's recent state of play.

2.1 Why Go?

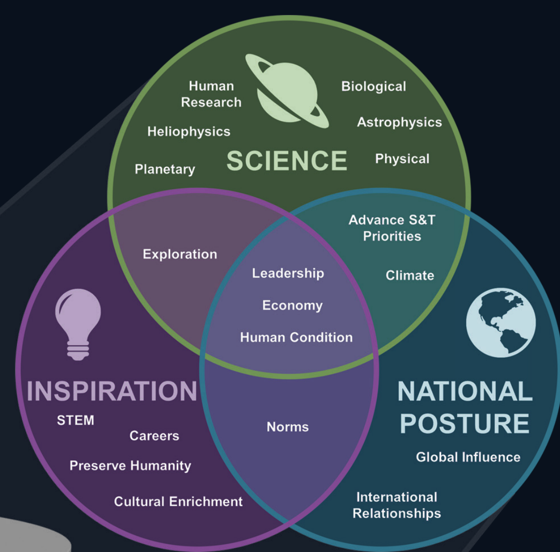
Systems engineering is predicated on the motivation, which is the fundamental goal. *Why do this?* For the blueprint vision and Moon to Mars endeavor, along with its goals, objectives and subsequent architectural wireframe, the question is: *Why send humans into space?*

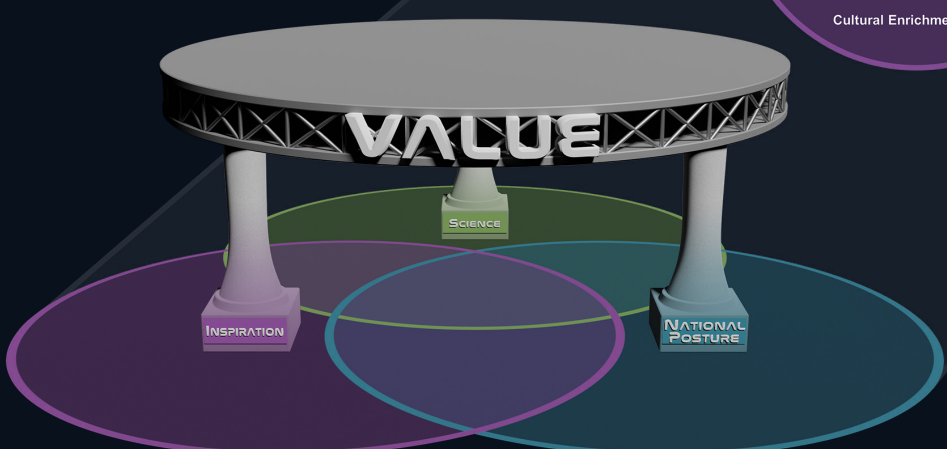
Creating a blueprint for sustained human presence and exploration throughout the solar system provides a value proposition for humanity that is rooted across three balanced pillars: **science**, **inspiration**, and **national posture**. Each pillar contains both unique and intersecting stakeholder values that together form the value proposition for the blueprint vision, starting with the Moon to Mars endeavor. While different individuals identify with different values, it's NASA's responsibility as a steward of taxpayer dollars to consider the entire landscape of motivating factors that underscore our society's answer to *Why Go?* Uniquely, by balancing all the factors, NASA positions the Moon to Mars strategy for longevity and success: It is not subject to whims or leadership overhauls. Instead, it is rooted deeply in a broadly relevant, largely unchanging value system.

So, *Why Go?* It's these three pillars, combined and with their intersections, that are why humans go into space.

WHY GO?

Humans go into space because there is inherent benefit of space exploration to humanity. Uniquely, NASA balances all the benefits to achieve a strategy that can withstand time and change. See Appendix A for more detail on the intersecting areas between pillars.



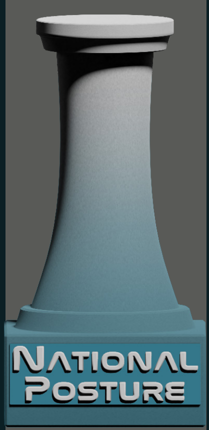


CATEGORIES OF BENEFITS

Science

The pursuit of scientific knowledge – exploring and understanding the universe – is integral to the human space exploration endeavor. Just as the James Webb Space Telescope informs about the history of time, answers gained on the Moon and Mars will build knowledge about the formation and evolution of the solar system and, more specifically, the Earth. From geology to solar, biological, and fundamental physics phenomena, exploration teaches about the earliest solar system environment: whether and how the bombardments of nascent worlds influenced the emergence of life; how the Earth and Moon formed and evolved; and how volatiles (e.g., water) and other potential resources were distributed and transported throughout the solar system. Space exploration teaches about human and plant physiology in extreme environments, how to mitigate engineering and health risks, as well as how to perform complex operations in harsh planetary environments. Space provides a unique vantage point to greatly amplify current learning on Earth. Biological and physical systems can be observed in reduced gravity, bringing out second and third order effects that are otherwise overwhelmed in the gravity environment. The history of our Sun is preserved in lunar soil, examination of which enables solar activity predictions and space weather forecasts, which in turn supports lunar and Martian exploration. Specific frequency ranges available for use only in space (due to interference by other Earth-based signals or the atmosphere) allow probing the deepest space and time of the universe. While remote sensing is a great aid, robotics and direct human engagement with and visitation of other bodies in the solar system ultimately reaps more data more effectively.

National Posture



By its very nature, achieving a vision of space exploration establishes national strength in science and technology innovation and competitiveness, which supports economic growth and global position. Hard technology problems solved in space have far-reaching implications for other Earth-based challenges and industries, and in many cases, spin off their own disciplines. For example, the term “software engineering” was crafted for the development of the guidance and navigation systems on Apollo spacecraft. Food safety standards and telemedicine likewise originated with NASA in an effort to enable longer duration human space flight. NASA technology, spin-offs, and investments fuel growth in American industry and support quality, high-paying jobs across the country. Specifically, NASA’s contracts and partnership with domestic commercial space has resulted in $15 billion in private investments in space start-up companies in a single year of this new era alone, with the majority of those investments in United States companies. Commercial space activity impacts other industries such as agriculture, maritime, energy, and homeland security, producing ripple effects throughout the economy. Additionally, because there are no geographic bounds in space, exploration lends itself to international partnerships to achieve feats that might not otherwise be possible. Bolstering international partnerships, economic competitiveness, and global influence likewise reinforces national security interests.

Inspiration

The “Moonshots” of the Apollo Program became a metaphor for how we as a nation could take on an audacious challenge and succeed through hard work and determination. The “Moonshot” metaphor has since been applied to inspiring and seemingly insurmountable challenges from curing cancer to developing fusion power. Apollo inspired a new generation of engineers and scientists in education and career pursuits supporting visionary work. The International Space Station and other space partnerships model how people from many nations can live and work together toward a common purpose. These next steps in space exploration can likewise inspire an all-new generation – the Artemis Generation – in science, technology, engineering and mathematics studies that support the great enterprises of voyaging into space and overcoming the most difficult challenges currently faced on Earth.

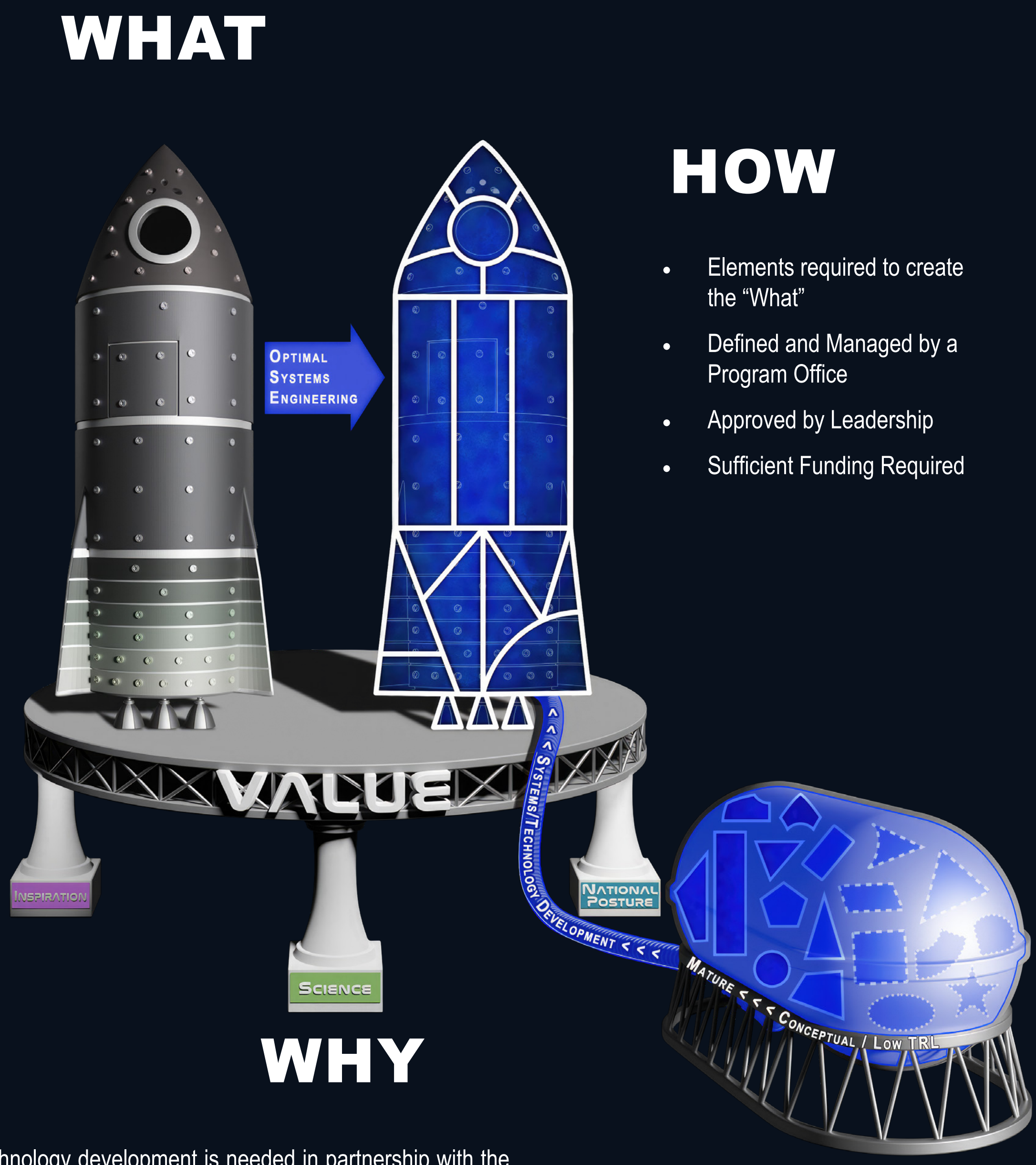
2.2 Optimal Systems Engineering

Following the optimal systems engineering approach, NASA leadership builds upon the foundational "why" platform to determine top-level goals and objectives for the human space exploration enterprise. This forms the "what", and should be:

- **detailed** enough to measure success;
- **rigorous** enough in development to outline achievable goals, and
- **consistent** with the motivation and future trajectory in order to withstand the test of time, technology, and outside influences.

Together, these guiding factors ensure the endeavor and its associated architecture are resilient in technical, financial, and political terms, including the ability to cross political administrations.

To continue to follow the optimal systems engineering process, after leadership identifies the "why" and develops the "what," the "how" must be filled in by a responsible organization assigned and empowered to complete this task – something akin to a Program Office. For Moon to Mars at NASA, that responsible organization is the Exploration Systems Development Mission Directorate (ESDMD). ESDMD will flesh out the elements required to achieve the blueprint goals and objectives, conduct trade studies and analyses of alternatives, and build out and gain approval on the architectural wireframe of activities and implementation. Funding is as vital as the plan: The endeavor and the systems engineering behind it must be sufficiently funded to accomplish such an architectural feat.



In order to flesh out the wireframe, technology development is needed in partnership with the Program Office to shepherd technology solutions from conceptual ideas to mature components that form the elements of the wireframe. When developed with an eye toward the blueprint vision, these technologies propel the architecture toward success. They can range from conceptual ideas (which are seed-corn for future space exploration approaches) to mature technologies ready for mission infusion, solving current and future needs. Technology development supporting the Moon to Mars endeavor pulls from a dedicated NASA mission directorate, as well as organic technology development inherent in agency-wide individual programs, international space agencies, and commercial work.

2.3 Systems Engineering Risks

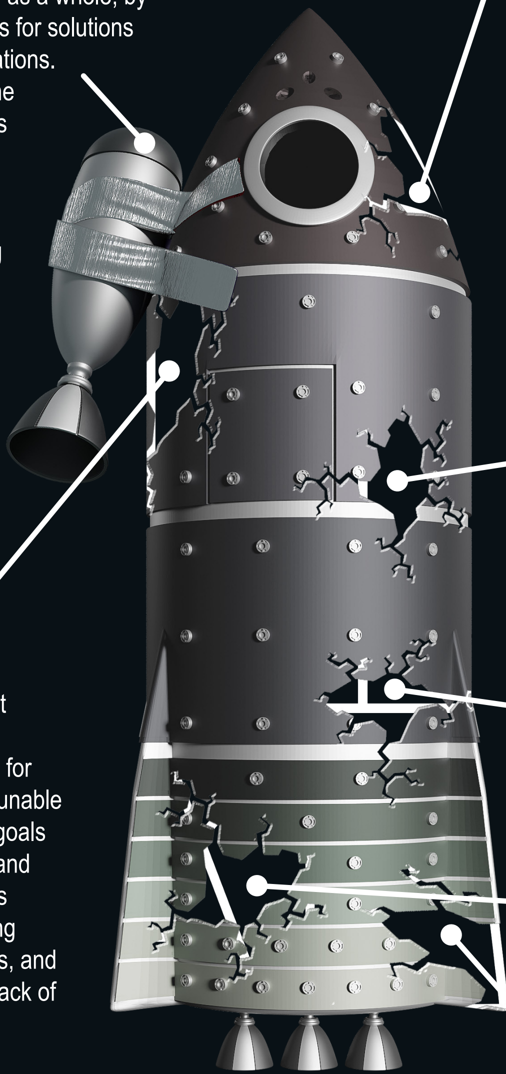
For optimal systems engineering to succeed, it's important to recognize risks that can impede progress, at best, or make the process crumble, at worst.

External Pressures

The systems engineering process is founded on rigor as a guiding principle to defining not only the goals and objectives, but also the technical solutions that comprise the wireframe. External stakeholders can jeopardize element development, or even the endeavor as a whole, by aborting the rigor and injecting ideas for solutions that stem from non-technical motivations. Acceptance of these ideas warps the wireframe because the technologies no longer directly map to the goals and objectives. At a minimum, this impedes the rigorously developed architecture. In some cases, adding unnecessary solutions diverts budgetary resources towards satisfying demand for out-of-scope programs and elements.

Insufficient Funding

The endeavor needs appropriate funding to succeed. Insufficient funding results in a "level of effort" approach, meaning only some individual elements are funded to the limit of the budget. This adversely alters the pace at which the endeavor can be accomplished to support the overarching vision, goals, and objectives. Such a funding pattern makes the endeavor inefficient at best and, in many cases, unsuccessful.



Broad/Changing Goals

If the vision is too broad, i.e., without the supporting goals and objectives (the "what"), there is too much room for interpretation and stakeholders are unable to focus their solutions. The vision, goals and objectives together must withstand time: any changes force the systems engineering process to reset, causing waste of time, money, and resources, and risk loss of buy-in. A direct result is lack of progress and increased cost.

Unhelpful Cultural Behaviors

Optimal systems engineering guides the workforce toward a common vision. If realized, any of the risks, or a combination thereof, can lead to unhelpful organizational cultural behaviors that frustrate the process:

Fears of Being Cut: If the blueprint strategy is not clearly articulated, with goals that are too broad and/or changing, the workforce is unable to see themselves in a unified plan, and so become fearful that their particular project will be cut. Rather than work together, it may cause competition for limited available resources.

Stovepipes: In fear and without clarity, the workforce creates stovepipes – focuses on individual architectural pieces with the goal of preserving and maturing them – without an eye toward an overarching, defined vision and strategy.

Poor/Restricted Communication: If fears and threats – real or perceived – materialize, internal communication can become limited, inconsistent, and self-promoting, impeding progress.

Distributed Motivations: The risks can feed isolation by forcing the workforce to individually envision its own raison d'etat.

A Deteriorating Cycle

If unhelpful cultural behaviors materialize, they can result in inconsistent external communication, causing the strategy to appear broken. This can make internal leadership question the strategy and create a desire from external stakeholders to attempt to "fix" the strategy. More – and deeper – risks materialize, which in turn, further degrades the workforce cohesion, which creates even more concern from stakeholders. This cycle's self-reinforcing nature becomes embedded in internal culture and erodes public trust of an organization's ability to execute the strategy. It is important to remember that industry, academia, and international partners can be as negatively affected by this deteriorating cycle as the NASA workforce and other government stakeholders.

2.4 Historical Context and Recent State of Play

To create an effective – and reliable – systems engineering process, it is also useful to understand the historical context that informs the revised strategy.

Moon to Mars Roller Coaster

The Moon to Mars endeavor finds its roots in 1989 with the presidential announcement of the Space Exploration Initiative (SEI). SEI was a broad vision for a low-Earth orbit space station, with the goal of establishing long-term human presence on the Moon and going beyond, to explore Mars. NASA's implementation plan, the Ride Report, faced external stakeholder opinion: It was not well received by the White House and Congress. In 1990, the Augustine Committee redirected NASA to focus on space and Earth science, transitioning human space exploration into a non-strategic, "go-as-you-pay" or level-of-effort strategy. The Committee preserved the Space Shuttle Program, which eventually led to development the International Space Station (ISS). Both the Space Shuttle Program and ISS development were punctuated by budget cuts that limited cohesion and progress. The vision started and stopped again in 2004 with the Vision for Space Exploration, and again in 2010, with similar patterns as before. The Moon to Mars roller coaster is a story of communication breakdowns, funding limitations, external stakeholder pressures, and broad and/or changing goals – all risks to the process that ultimately limited progress.

Capability-Based Framework

From 2010 to approximately 2020, NASA leadership and U.S. legislators created the compromise that led to the Space Launch System, Orion spacecraft, and the Exploration Ground System – the formation of the Artemis program. Changing goals and budget questions regarding legislated technology solutions and affordability caused anxiety – internal and external to NASA – and led to the "capability-based" approach. These capabilities would enable the agency to go to any destination legislators chose – cislunar space, the lunar surface, near-Earth asteroids, Mars, or anywhere else – while not necessarily accounting for the specific needs of each destination. The capability-based approach addresses the question: What can be done with the existing budget? While the capability-based approach makes progress, it's not the same progress enabled by an objective-based strategy. It allows for the development of technology but lacks a vision of the end state for that work.

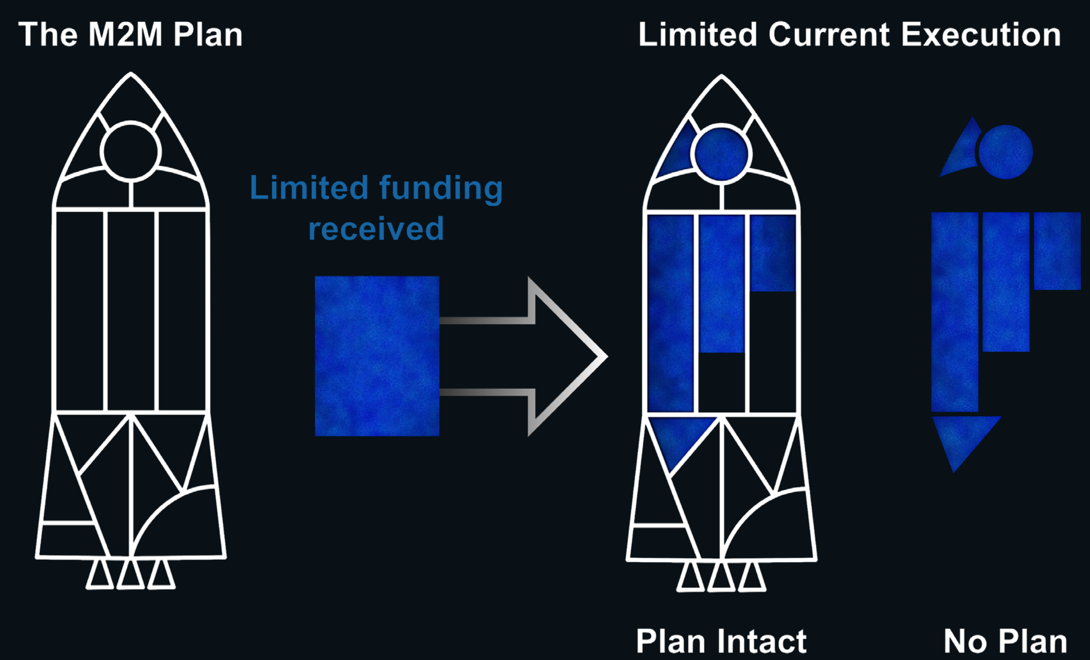
Inflection Point

The capability-based framework and the agency's space exploration work since the 1950s forms the foundation of human exploration systems on which a new strategy can build. Moving forward, an objective-based strategy will achieve a blueprint for sustained human presence and exploration throughout the solar system. The new Moon to Mars strategy steps back to consider what has been done and what must be done to step forward farther and more meaningfully into space exploration. The new strategy must be specific, rigorous, and consistent, creating resilience – in technical, financial, and political terms – for it to gain universal understanding and unification of effort. At the same time, the strategy must be flexible, for new minds, new technologies, new approaches, and new learning to help shape any evolution in the coming decades in a similarly rigorous manner.

Communication Breakdown

As the capability-based framework unfolded, there was a quiet desire to keep an eye on a long-term plan that could maintain momentum and create strategic progress in a resource-constrained environment. NASA leadership developed such a strategy, but it was not clearly or widely communicated throughout the agency. It was as if the wireframe – the fundamental structure that holds the endeavor together – had disappeared. Programs and elements were being developed without a clear understanding of how it all fit together into a long-term plan, and the Moon to Mars endeavor once again fell victim to systems engineering risks.

Graphical example of a deteriorating strategy due to lack of funding and/or communication. In the optimal structure, funding limitations are strategically prioritized according to the wireframe architecture, with an eye toward the clearly articulated vision, goals, and objectives. On the far right, the wireframe disappears without clear communication and understanding, leaving a "cloud pattern" of funded activities. In the vicinity of the blue fields, one can intuit the connections, but the rest of the wireframe is left to individual guesswork.



In several critical ways, the new space exploration landscape is different than it was between 1989 and 2022. At this inflection point, NASA has had the opportunity to stay the course over two consecutive political and agency administrations. At the same time, the threat of international space exploration competition looms. The first wave of commercial space sector partners are successfully operating, and the cost to orbit and the size of robotic spacecraft have reduced dramatically. The commercial sector has proven that once NASA demonstrates a technology, it can successfully carry technologies forward and provide space transportation as a service. It's an era where a new generation of innovators is revolutionizing space exploration and operations. An objective-based strategy founded on excellence in systems engineering will continue the forward progress and inspire the investments necessary to forge ahead in space exploration.

3.0 METHODOLOGY PRINCIPLES

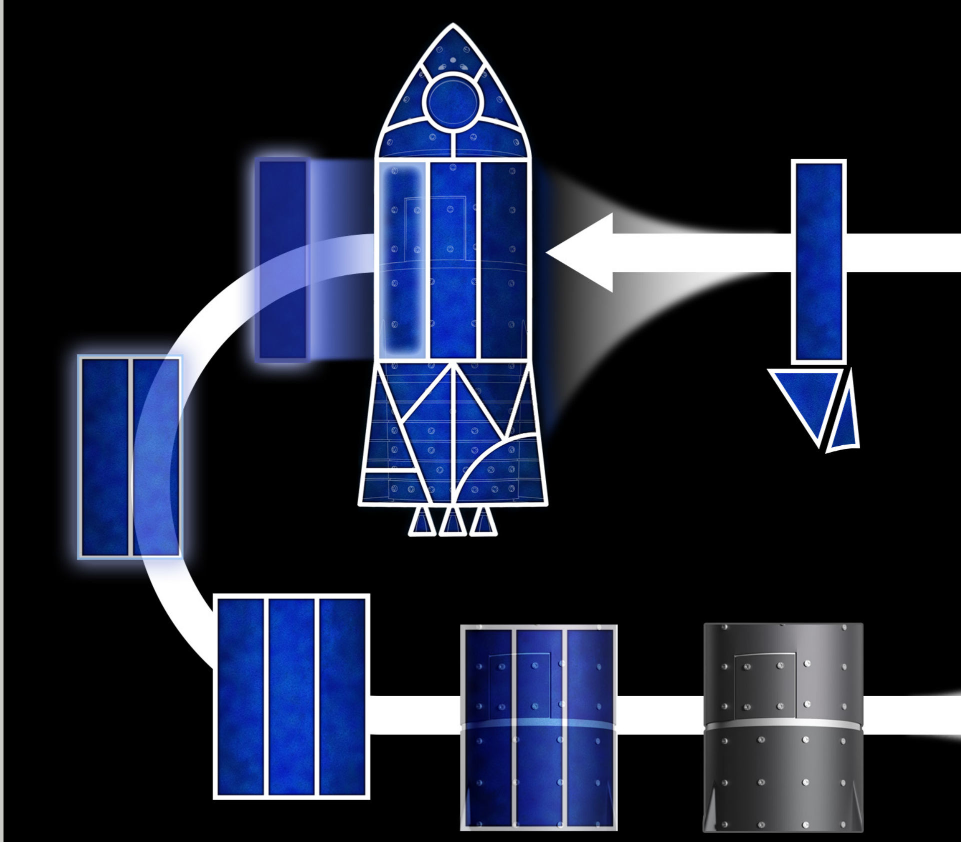
NASA's Moon to Mars strategy is guided by both a robust systems engineering process and five interrelated methodology principles.

Objective-Based Approach

The first principle is a shift from a capability-based framework to an objective-based framework, in which top-level goals and objectives lead, guiding the integrated plan to meet them. The objective-based approach looks to the future and codifies an envisioned long-term state (the "what" in the systems engineering process). In a schedule vernacular, this envisioned long-term goal is how things look all the way to the right on the schedule. Through goals and objectives developed in detail, with rigor, with consistency across years and administrations, and with a mind toward value, an objective-based approach can guide the agency through external influences toward the strategic vision. Strategically developing the Moon to Mars endeavor lays the foundation for the long-term vision ("create a blueprint for sustained human presence and exploration throughout the solar system") and allows for demonstration of the blueprint on Mars. Going to the Moon is in part to prepare for that initial Mars campaign.

Architect from the right – work backwards from the defined goal and establish a complete set of elements that will be required for success.

Architect from the Right / Execute from the Left



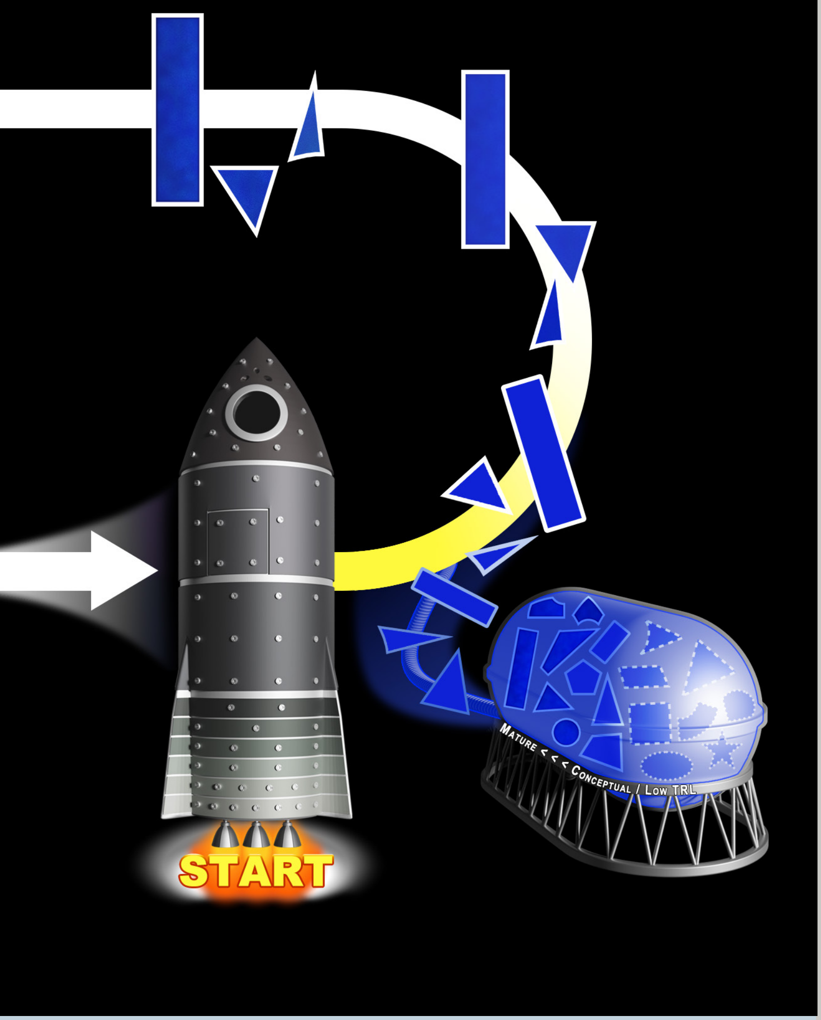
Execute from the Left

Once the wireframe is fully architected by looking toward the future state, element development follows from the left, integrating into the blueprint architecture as development advances.

With the long-term goals and supporting objectives established, the architectural approach starts from the right (the desired end state) and works backward to decompose the goals and objectives into a complete set of elements, systems, subsystems, etc. required to achieve success. By anchoring efforts toward the end state, this process of architecting from the right can be carried down with increasing specificity to establish a full plan. Once the wireframe is fully

The top-level goals and objectives, combined with the blueprint vision statement, form the complete "what" to the Moon to Mars systems engineering process.

Architect from the Right



architected by looking toward the future state, element development follows from the left, integrating into the blueprint architecture as development advances.

For the Moon to Mars strategy, the first step in Architecting from the Right was to establish the blueprint vision and identify the goals and top-level objectives to achieve that vision.

Constancy of Purpose

Once documented with clarity, the blueprint vision, top-level goals and objectives, and overall endeavor remains consistent and resilient over time for all stakeholders, including industry, academia, international partners, government, and the NASA workforce:

- **Technical resilience:** Sound and rigorous technical analysis is the backbone of technical credibility. By being technically sound, the blueprint architecture is easily understood by the workforce, which in turn can accurately and consistently communicate the implementation plan internally and externally.
- **Financial resilience:** In the face of inevitable budgetary constraints, rather than abandon the rigorously defined plan to accommodate a reduced budget, the architecture assists with maximizing potential. The strategy and resulting wireframe help prioritize efforts, as well as identify opportunities when the resource environment improves.
- **Political resilience:** An endeavor founded on a concrete values system, that has well-crafted goals and objectives, and is architected with integrity, produces trust in an efficient system that's targeting a valuable vision – making it resilient across political administrations.

Constancy does not preclude change. New technical insights, new minds, new discoveries, and more can all influence the endeavor. However, recommended changes must undergo the same rigor the original architecture underwent. Changes cannot be arbitrary or non-technical.

Unity of Purpose

A house divided against itself cannot stand. Unity of Purpose, together with Constancy, are vital for a major endeavor like Moon to Mars. Ideally, the workforce is working to the same drumbeat internally and speaking the same language externally. Fully aligned, the process is successful. All stakeholders should understand and be able to articulate the vision, goals, and objectives of the endeavor. All members should have clarity on their role yet be flexible to create the optimum chance for success. Consistency in answers from NASA about strategy, efforts, and purpose are paramount. By understanding the blueprint architecture, every member of the workforce becomes an emissary for the Moon to Mars endeavor. To further facilitate unity, the strategy must include a structured assessment and adjustment process to the greatest extent practical, based on feedback from the workforce, the public, and stakeholders. By understanding how the plan is developed and updated, members who are concerned with a particular aspect of the architecture will know exactly how to engage in the improvement process, rather than express discontent by promoting an individual version of the plan.

Communication is the lifeblood that drives the reinforcing cycle of the all the other principles, and ultimately promotes political resilience.

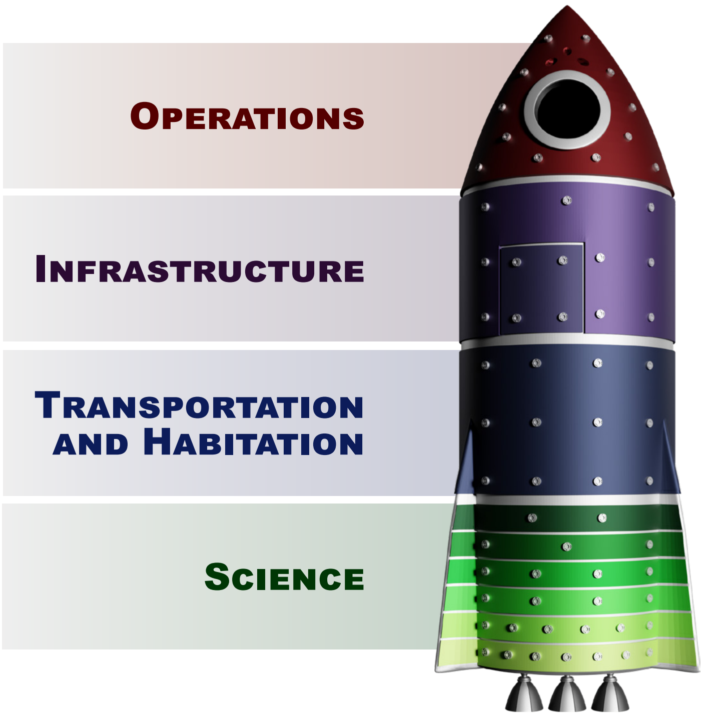
Enhanced Communication and Engagement

Communication and engagement catalyze understanding, unity, constancy, technical credibility, and resilience. With communication and engagement comes the best chance at success. Communication reinforces all other principles, and enhances political resilience. It also bolsters public awareness and support for the Moon to Mars strategy through robust outreach and engagement efforts. It enhances collaboration efforts with international partners, industry, and academia to achieve common goals and objectives. Communication also allows continuous engagement with the NASA workforce to promote understanding, inform workforce roles, and solicit feedback on a regular basis.

Communication and engagement have long been strengths for NASA, so this principle builds on those successes to underscore for internal and external stakeholders the Moon to Mars strategy itself, its development, and its importance. This document has already started off with this principle in mind: NASA's Cross-Directorate Federated Board, an internal coordination body whose membership includes senior leadership from each of the mission directorates, was created to ensure the directorates are cohesively focused on and integrated with common strategic goals and direction for the agency. The Federated Board promotes excellence in communication across NASA, helps drive consensus, fosters efficient conflict resolution, and provides advice to decision-makers. The Federated Board promoted the agency's first steps in Architecting from the Right in a collaborative way by drafting the initial set of top-level objectives, as well as soliciting public feedback and utilizing that feedback to refine the objectives. The Federated Board is also the primary author of this document, which is the cornerstone of communication efforts surrounding the Moon to Mars strategy.

4.0 OBJECTIVES DEVELOPMENT

In November 2021, NASA leadership began to identify top-level goals and objectives related to the blueprint vision and Moon to Mars strategy. The Federated Board facilitated approval of these goals and objectives, which were binned into four distinct tracks:



The original nine goals and 50 draft objectives were released to the public and the NASA workforce in May 2022 with a request for comments by June 2022. NASA received more than 5,000 inputs, which resulted in modification of many objectives and the addition of several new ones. NASA held consultation workshops with both industry and international partners to continue to refine the objectives and identify gaps, welcoming the substantive and influential feedback.

The resulting revised 10 goals and 63 final objectives reflect a matured strategy for NASA and its partners to develop a blueprint for sustained human presence and exploration throughout the solar system via the Moon to Mars endeavor. In addition to the four tracks of goals and objectives, a set of recurring tenets addresses common themes across objectives. More details of the objectives development process can be found in Appendix B: Objectives Development Process.

5.0 REVISED OBJECTIVES WITH RATIONALE

The final set of 63 top-level objectives and their corresponding goals, along with the rationale behind each goal, combine with the blueprint vision to form the "what" NASA is aiming to achieve. Together with the value proposition, or "why", it is the foundation of the systems engineering process. The goals and objectives are top-level enough to not mandate particular technical solutions or acquisition approaches, detailed enough to judge success, rigorously developed over nine months to make them resilient, and consistent with the value proposition and future trajectory.

**Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM).*

Recurring Tenets

The Recurring Tenets (RTs) capture common themes that are broadly applicable across the objectives. The nine RTs describe aspects of strategy that are fundamental to achieving the Moon to Mars objectives. Neglecting any of the RTs in pursuit of an objective could hinder or even prevent successful execution of the Moon to Mars endeavor.

Rationale for some of the RTs is readily apparent. For example, returning crew safely and mitigating impacts to their health **(RT-3)** is fundamental to a successful human space exploration campaign. So too is maximizing crew time for high-value activities **(RT-4)** and minimizing the amount of time required for maintenance and other support tasks. Meanwhile, international and industry partnerships **(RT-1 and RT-2)** seem similar on the surface, but nuances exist in engaging with each stakeholder group, so each merits a designated tenet. As shown by the International Space Station and other recent space exploration efforts, international and industry partnerships each bring dissimilar redundancies and a variety of solutions that increase the chances of campaign success and longevity. To further leverage existing programs and partnership strategies, **RT-8** acknowledges the value of utilizing and enhancing commercial low-Earth orbit infrastructure in the strategy, where appropriate.

Other recurring tenets reflect the need for sustainability and interoperability, which surfaced as common themes in stakeholder workshops and written comments. Sustainability and interoperability are underlying assumptions in the planned architecture development, but these public inputs highlight the need to communicate this intent within the framework of the objectives. **RT-5** – maintainability and reuse – captures the need for maintainable systems to reduce logistics, promote extensibility, and increase operational independence from Earth over time. **RT-6** – responsible use – was crafted through robust discussions, particularly with international partners and the science community. It centers on preserving the lunar and Martian environments and protecting science value at high-interest sites. RT-6 also includes considerations associated with international commitments, norms of behavior, and national regulations. **RT-7** on interoperability reflects discussions with numerous international and industry partners and recognizes the need for standards on technical requirements, design processes, operations, and other aspects of mission planning and execution, as early in the planning process as possible, to ensure mission success and efficiency. Technology destined for the Moon or Mars will need to integrate, no matter the provider, and perhaps in ways the campaigns don't initially foresee.

Finally, **RT-9** emphasizes the importance of supporting industry efforts to both develop innovative solutions to campaign needs and to lay the groundwork for expanding the capabilities demonstrated by and developed for Moon to Mars activities. This recurring tenet fosters a sustainable cislunar economy. It also captures potential benefits through spinoff technologies and other downstream impacts on Earth.

Recurring Tenets

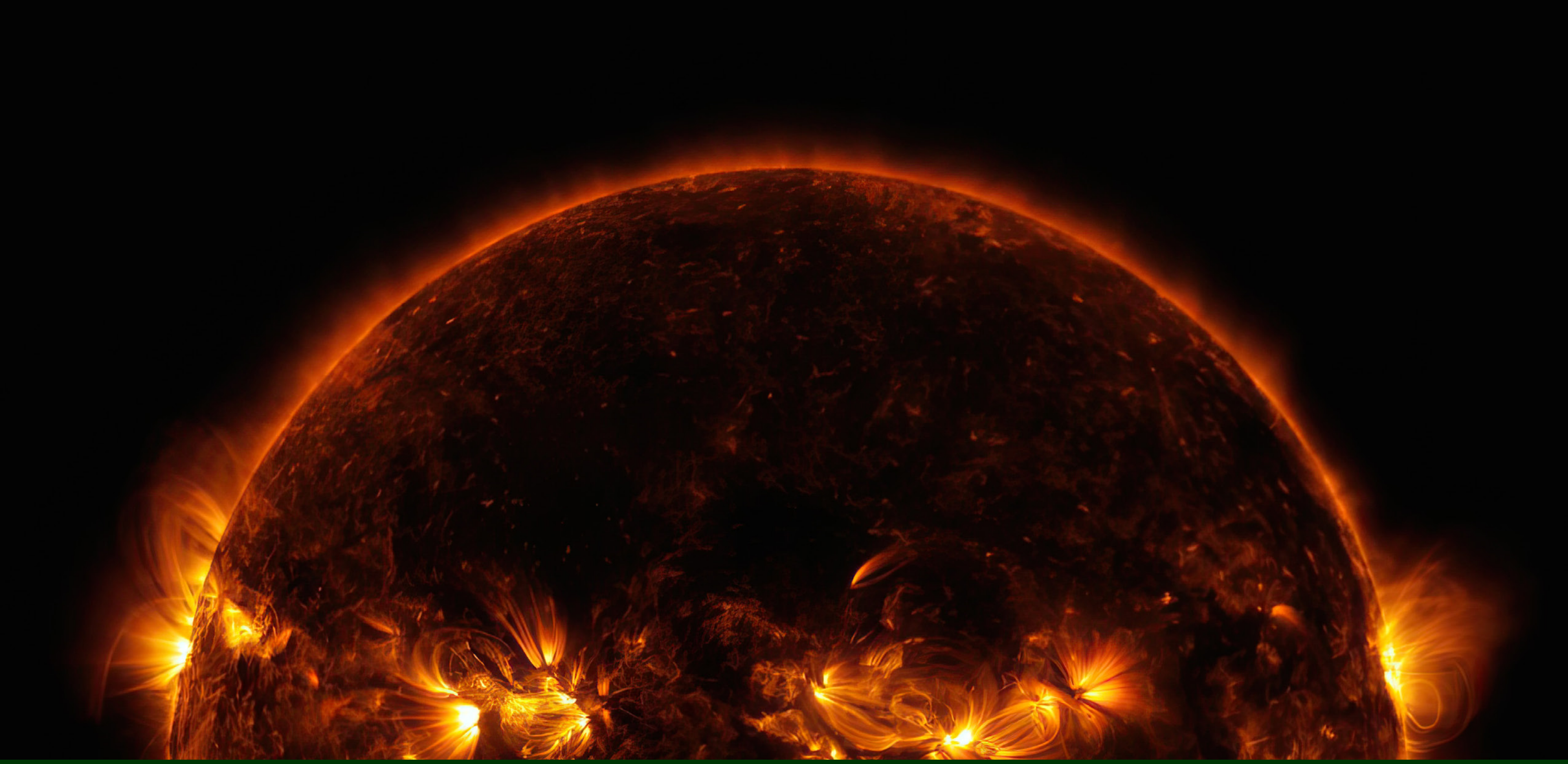
RT-1:	International Collaboration: Partner with the international community to achieve common goals and objectives.
RT-2:	Industry Collaboration: Partner with U.S. industry to achieve common goals and objectives.
RT-3:	Crew Return: Return crews safely to Earth while mitigating adverse impacts to crew health.
RT-4:	Crew Time: Maximize crew time available for science and engineering activities within planned mission durations.
RT-5:	Maintainability and Reuse: When practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.
RT-6:	Responsible Use: Conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space.
RT-7:	Interoperability: Enable interoperability and commonality (technical, operations and process standards) among systems, elements, and crews throughout the campaign.
RT-8:	Leverage low-Earth orbit: Leverage infrastructure in low-Earth orbit to support Moon to Mars activities.
RT-9:	Commerce and Space Development: Foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation.

Lunar/Planetary Science (LPS)

Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

LPS-1[LM]:	Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moon and Mars.
LPS-2[LM]:	Advance understanding of the geologic processes affecting planetary bodies by determining interior structures, characterizing magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.
LPS-3[LM]:	Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.
LPS-4[M]:	Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.

Rationale: Billions of years of solar system events are recorded within the regolith and craters of the lunar surface, making the Moon a cornerstone to planetary science. Access to the lunar interior from large impact craters and studies of volcanism on the Moon (and subsequently, on Mars) yield new discoveries about planetary differentiation and geologic history. Strategic science and sampling campaigns by crewed missions enable new insights into planetary formation, evolution, bombardment history of the inner solar system, and prebiotic chemistry leading to new theories on habitable biospheres and the search for life in our solar system and beyond.



Heliophysics Science (HS)

Goal: Address high-priority heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

HS-1^{LM}:	Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.
HS-2^{LM}:	Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.
HS-3^{LM}:	Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.
HS-4^{LM}:	Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.

Rationale: Observing the space environment from the Moon and Mars allows for measurements of the solar wind not possible from Earth. These measurements are fundamental to unlocking an understanding of the nature of the Sun, the dynamic processes of space weather, and building knowledge valuable for comparative planetology and habitability. Lunar and Martian regolith contains a scientific record of the history of solar activity as seen at the surface of bodies in the solar system.

Human and Biological Science (HBS)

Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, to support safe, productive human space missions, and to reduce risks for future exploration.

HBS-1[LM]:	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
HBS-2[LM]:	Evaluate and validate progressively Earth-independent crew health and performance systems and operations with mission durations representative of Mars-class missions.
HBS-3[LM]:	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.

Rationale: Missions beyond low-Earth orbit represent an opportunity to gather data to characterize the effects of the Moon, Mars, deep space, and the operational environment on astronauts and biological systems that enable learning about and addressing key elements of NASA's Five Hazards of Human Spaceflight. These experiments will aid in identifying and understanding underlying physiological, biochemical, and molecular mechanisms of human physiology and crop plants that drive biological responses and facilitate adaptation to the exploration environments. Exposure of humans and non-human biological systems to the environments in and around extraterrestrial bodies (beyond the Earth and the International Space Station) are critical to investigating and understanding how living systems respond and adapt to the hazards of spaceflight. These findings are fundamental to a sustained human presence in our solar system and maintaining high levels of human performance, health, and safety amidst the stress and strain of the space environment in general, and specifically, in the journeys to and time spent exploring the Moon and Mars.

Physics and Physical Science (PPS)

Goal: Address high-priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

PPS-1^{L}:	Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.
PPS-2^{LM}:	Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

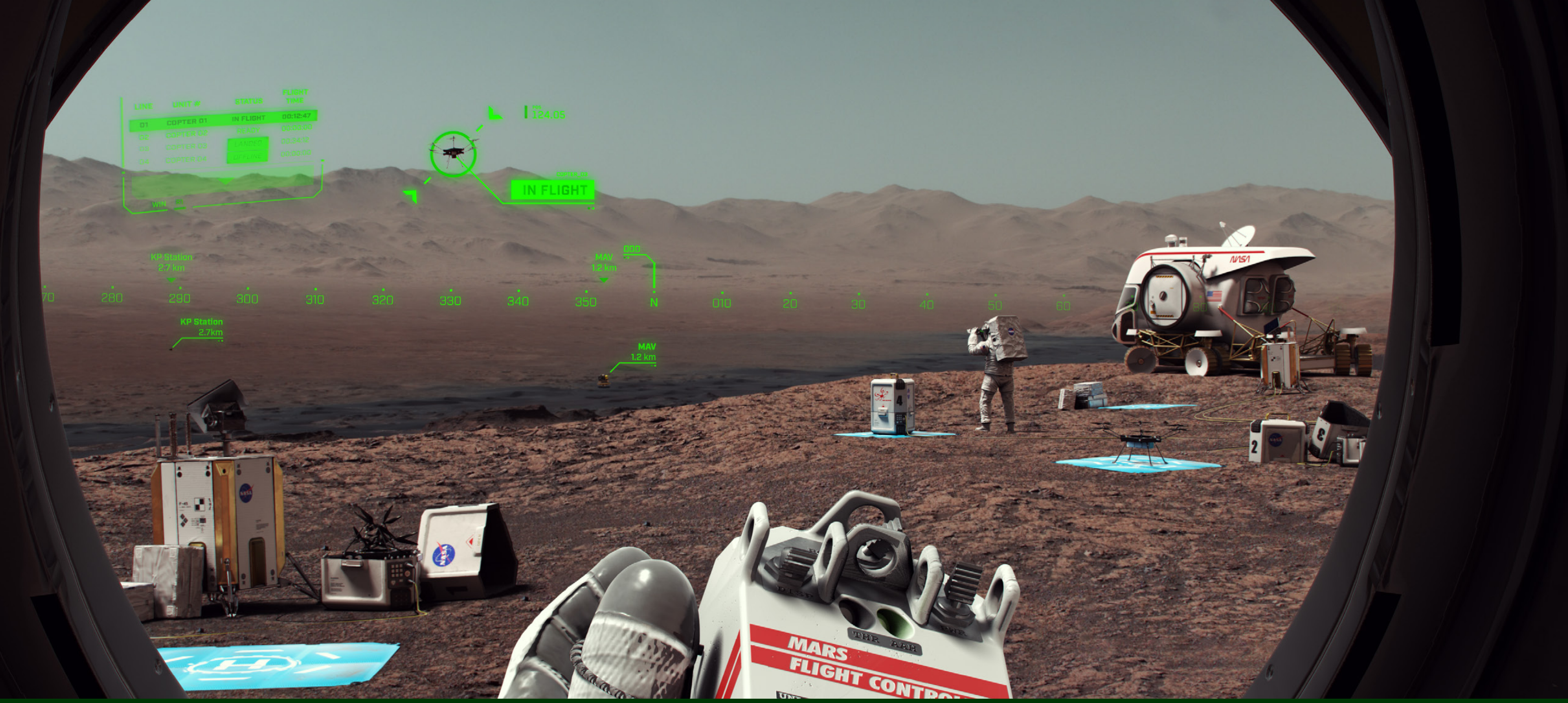
Rationale: The Moon unlocks transformative scientific research in astrophysics, fundamental physics, and physical sciences that cannot be accomplished on Earth or in low-Earth orbit. Research at the Moon is essential to obtain data for advancing scientific discovery and knowledge and to develop technologies to achieve Moon to Mars goals and objectives. For astrophysics, the radio quiet far side of the Moon allows for sensitive low frequencies radio astronomy observations of the Universe, which complement and go beyond the Webb Telescope. Also, full-disk Earth viewing leads to investigations of exoplanets and how we can begin to recognize signs of life/habitability around other stars. The surface of the Moon enables investigations into the physics of regolith and planetary dusts, and is an ideal platform for experiments in general relativity and quantum physics. The Moon's gravity enables investigations to understand how physical systems essential for expanding human presence and capabilities in space perform in planetary environments. Understanding the dynamics of physical systems in lunar and Martians environments is essential for in-space/lunar and Mars surface manufacturing, deep space propulsion, in-situ resource utilization, and sustaining human health.

Science-Enabling (SE)

Goal: Develop integrated human and robotic methods and advanced techniques that enable high-priority scientific questions to be addressed around and on the Moon and Mars.

SE-1^{LM}:	Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.
SE-2^{LM}:	Enable Earth-based scientists to remotely support astronaut surface and deep space activities using advanced techniques and tools.
SE-3^{LM}:	Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.
SE-4^{LM}:	Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.
SE-5^{LM}:	Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.
SE-6^{LM}:	Enable long-term, planet-wide research by delivering science instruments to multiple science-relevant orbits and surface locations at the Moon and Mars.
SE-7^{LM}:	Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.

Rationale: A certain level of infrastructure and operations must exist to enable discipline-specific science objectives listed in the LPS, HS, HBS, and PPS goals to be achieved. The Science-Enabling objectives address the most critical capabilities and operations to accomplish transformative science investigations on and around the Moon and Mars.

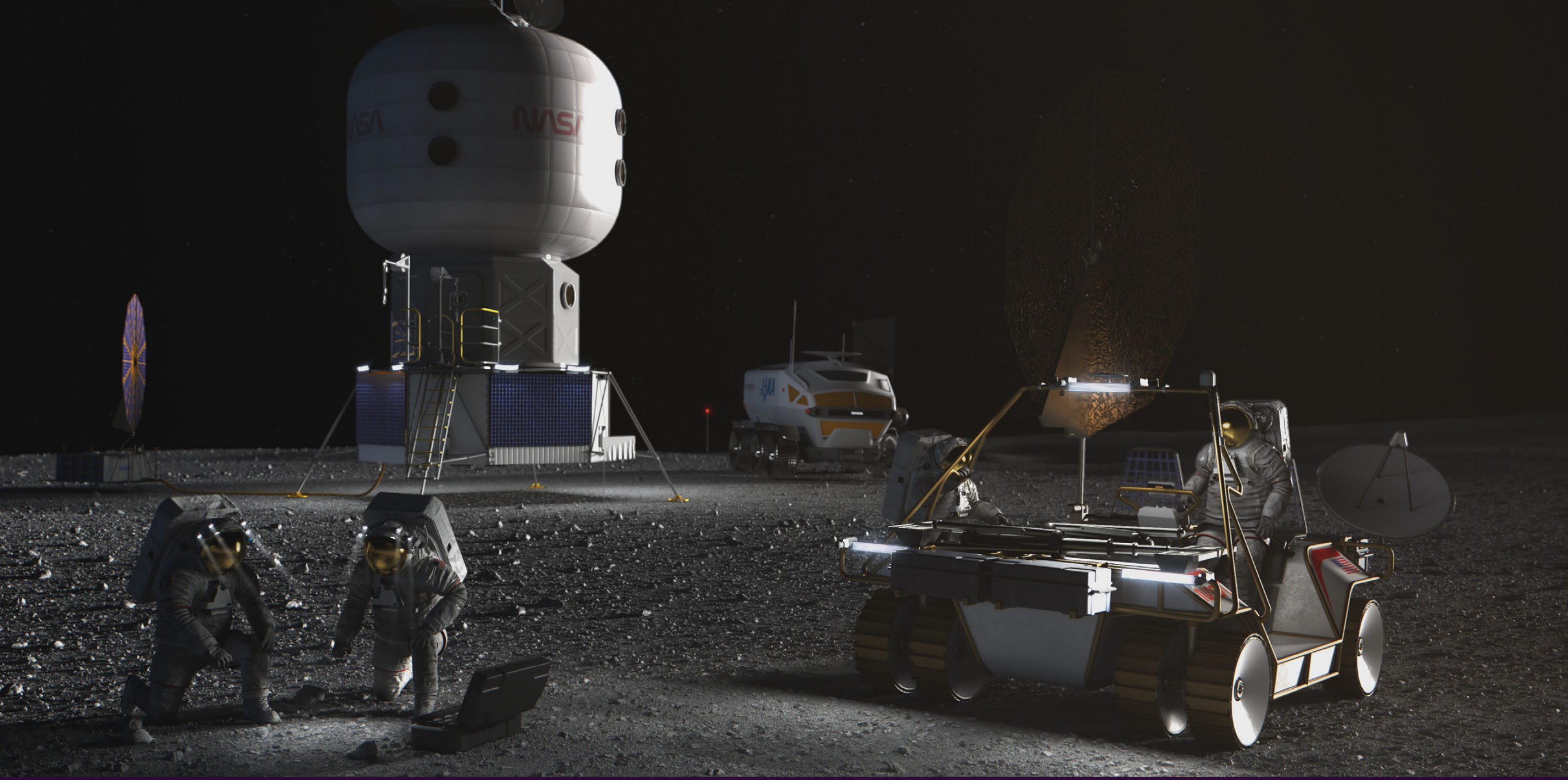


Applied Science (AS)

Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

AS-1LM:	Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.
AS-2LM:	Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.
AS-3LM:	Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.
AS-4LM:	Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems.
AS-5LM:	Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.
AS-6LM:	Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.

Rationale: Applied Science objectives aim to show how dedicated science investigations lay the groundwork to enable other organizations to effectively design architectures or buy down risk associated with humans or robotic assets operating safely and effectively on planetary surfaces.



Lunar Infrastructure (LI)

Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

Rationale: This goal articulates the foundational capabilities and services required to support continuous human presence and exploration of the Moon. The intention is to enable access and support across the entirety of the Moon's surface, not limiting exploration to one location or region that constrains scientific gain or extension to Mars. The language of this goal reinforces the important tenet of inviting industry and international partners to fully participate in and contribute to this endeavor. It supports the creation of markets and services that can endure with commercial value. Finally, this goal reinforces the key drivers for lunar exploration, which are scientific gains and practice for Mars.

One objective for each major infrastructure technology reflects the expectation that these capabilities will be achieved on different time scales and phased accordingly, and that their completion will be assessed by different metrics. **LI-1 through LI-3** address the overarching "utilities," that will be needed to support continuous lunar presence: power; communications; and position, navigation, and timing. These areas are fundamental elements that are essential to multiple scales of exploration throughout the build-up of assets on the lunar surface. **LI-4 through LI-6** describe additional primary capabilities that will enable robust exploration and sustained presence: mobility, precise landings, and manufacturing and construction. **LI-7 and LI-8** are the advanced capabilities that suggest industrial scale production and a fundamental shift to the use of lunar surface resources for sustainment and reduced logistics from Earth. **LI-9** explicitly calls out some of the functions that will provide resilience and situational safety for astronauts and assets.

LI-1ᴸ:	Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.
LI-2ᴸ:	Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-3ᴸ:	Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-4ᴸ:	Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-5ᴸ:	Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-6ᴸ:	Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-7ᴸ:	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-8ᴸ:	Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
LI-9ᴸ:	Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

Mars Infrastructure (MI)

Goal: Create essential infrastructure to support an initial human Mars exploration campaign.

Rationale: To enable the potential for human presence and exploration of Mars beyond one mission, this goal acknowledges that foundational capabilities and services will be needed to properly prepare for and support this challenging endeavor. As technologies mature and the Mars architecture evolves, the exact meaning of the word “campaign” and the supporting objectives will be further defined.

As with the Lunar Infrastructure Objectives, the Mars Infrastructure Objectives are broken into specific functions that are foundational to efficient, safe, and sustained human exploration in **MI-1 through MI-3**: power; communications; and position, navigation and timing. **MI-4** reflects the importance of long-lead technology developments demonstrating the use of in-situ resources for repeated exploration missions and future sustained presence.

MI-1ᴹ:	Develop Mars surface power sufficient for an initial human Mars exploration campaign.
MI-2ᴹ:	Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.
MI-3ᴹ:	Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.
MI-4ᴹ:	Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.

Transportation and Habitation (TH)

Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human exploration missions to the Moon and Mars, while living and working on the lunar and Martian surfaces, with safe return to Earth.

Rationale: This goal enables all other human exploration goals in that it addresses three fundamental aspects of human exploration: transportation of crew and cargo to and from a destination, maintaining crew health and safety during the journey, and maximizing crew productivity to best accomplish the vision. The Transportation and Habitation Objectives required to achieve this goal are further broken down into three groupings.

TH-1 through TH-8 address humanity's reach beyond low-Earth orbit, to the lunar vicinity and its surface, and to the Mars sphere of influence and its surface. The extension of human activity to the Moon and Mars requires the development, demonstration and application of transportation and habitation systems, supporting infrastructure, and logistics for sustained operations. Unique systems are required for orbital and surface access, habitation, and operations.

TH3, TH7, TH9, and TH10 enhance the crew's capabilities beyond transport and survival at the destinations. They identify crew support systems that minimize overhead labor and maximize the ability to achieve science and utilization objectives unique to crewed exploration. For example, optimizing human/robotic interrelationships to maximize exploration efficiency.

TH11 and TH12 realize benefits to humanity through human exploration by outlining the need for increased cargo/payload return from the exploration destinations. As crew productivity and exploration time increase, so too will the quantity of scientific samples and other products to be returned to Earth. As the exploration timeline progresses, increased cargo return from the lunar surface will benefit space economy opportunities.

TH-1^{L}:	Develop cislunar systems that crew can routinely operate to and from lunar orbit and the lunar surface for extended durations.
TH-2^{L}:	Develop system(s) that can routinely deliver a range of elements to the lunar surface.
TH-3^{L}:	Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.
TH-4^{LM}:	Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
TH-5^{M}:	Develop transportation systems that crew can routinely operate between the Earth-Moon vicinity and Mars vicinity, including the Martian surface.
TH-6^{M}:	Develop transportation systems that can deliver a range of elements to the Martian surface.
TH-7^{M}:	Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.
TH-8^{LM}:	Develop systems that monitor and maintain crew health and performance throughout all mission phases, including during communication delays to Earth, and in an environment that does not allow emergency evacuation or terrestrial medical assistance.
TH-9^{L}:	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during lunar missions.
TH-10^{M}:	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during Martian missions.
TH-11^{L}:	Develop systems capable of returning a range of cargo mass from the lunar surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.
TH-12^{M}:	Develop systems capable of returning a range of cargo mass from the Martian surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.

Operations (OP)

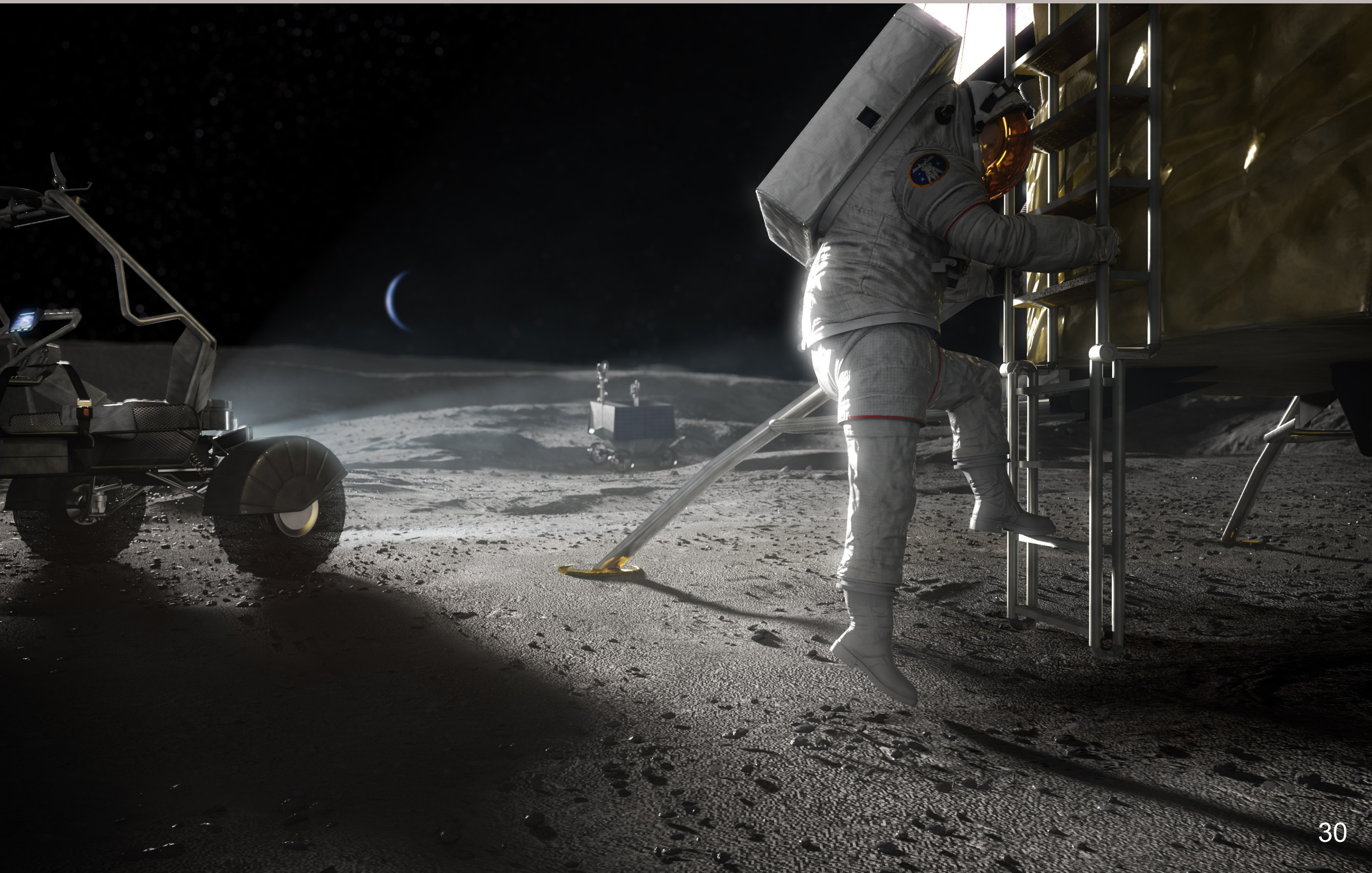
Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

OP-1[L]:	Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the Moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.
OP-2[LM]:	Optimize operations, training, and interaction between the team on Earth, crew members on orbit, and a Martian surface team, considering communication delays, autonomy level, and time required for an early return to the Earth.
OP-3[LM]:	Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.
OP-4[LM]:	Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
OP-5[LM]:	Operate surface mobility systems, e.g., extra-vehicular activity (EVA) suits, tools and vehicles.
OP-6[L]:	Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.
OP-7[LM]:	Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.
OP-8[LM]:	Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.

OP-9LM:	Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.
OP-10LM:	Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms.
OP-11LM:	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
OP-12LM:	Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.

Rationale: NASA was tasked with leading an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.

NASA's Moon to Mars Operations goal and objectives are intended to reflect NASA's operational interpretation of U.S. government policy by describing the key accomplishments that will lead to the fulfillment this policy in human exploration. The operational objectives both encompass and enable all other human exploration goals and objectives while focusing on the total system performance, crew health and safety, and the responsible use of resources.



Objectives Glossary

Architecture: A set of functional capabilities, their translation into elements, their interrelations, and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

Campaign: A series of interrelated missions that together achieve agency goals and objectives.

Continuous Presence: Steady cadence of human/robotic missions in subject orbit/surface with the desired future state of 365/24/7 operations.

Demonstrate: Deploy an initial capability to enable system maturation and future industry growth in alignment with architecture objectives.

Develop: Design, build, and deploy a system, ready to be operated by the user, to fully meet architectural objectives.

Explore: Excursion-based expeditions focused on science and technology tasks.

Global: Infrastructure and capabilities that support human and robotic operations and utilization across the subject planetary surface.

Incremental: Building compounding operational capabilities to achieve a goal within the constraints of schedule, cost, risk, and access.

Live: The ability to conduct activities beyond tasks on a schedule. Engage in hobbies, maintain contact with friends and family, and maintain healthy work-life balance.

Mission: A major activity required to accomplish an agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an agency goal. Mission needs are independent of any particular system or technological solution.

Mobility: Powered surface travel that extends the exploration range beyond what is possible for astronauts to cover on foot. Spans robotic and crewed systems, and can be accomplished on and above the surface.

Routine: Recurring subject operations performed as part of a regular procedure rather than for a unique reason.

Scalability: Initial systems designed such that minimal recurring Design Development Test and Evaluation (DDT&E) is needed to increase the scale of a design to meet end state requirements.

Utilization: Use of the platform, campaign and/or mission to conduct science, research, test and evaluation, public outreach, education, and industrialization.

Validate: Confirming that a system satisfies its intended use in the intended environment (Did we build the right system?).

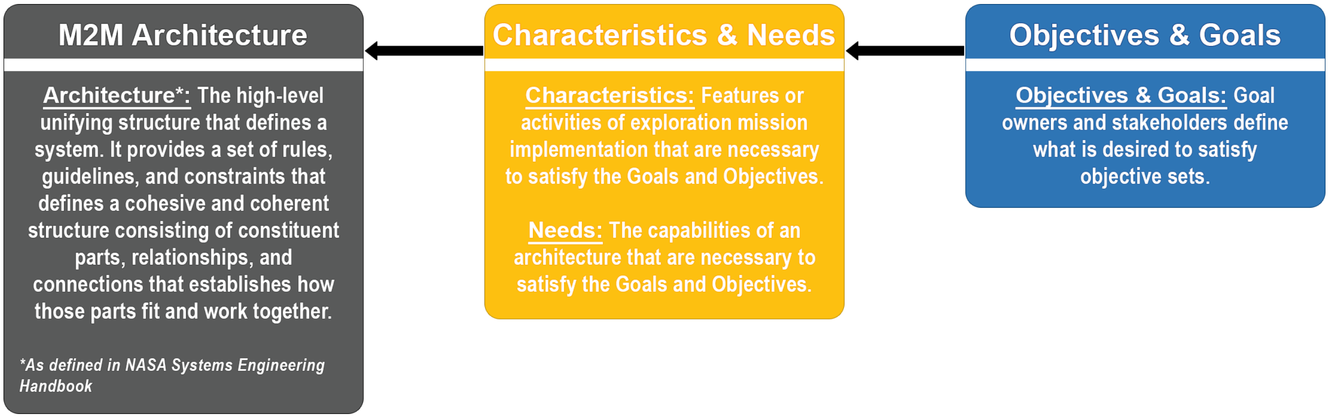
These definitions apply to the goals, objectives, and recurring tenets and do not supersede other definitions used by NASA in their specific contexts.

6.0 WHAT'S AHEAD

Objectives Decomposition

Within NASA, the Exploration Systems Development Mission Directorate will lead the blueprint architecture development necessary to meet the goals and objectives of the human centric campaign. The wireframe of goals and objectives, developed from the right, will guide the "how" of the systems engineering process and will outline the exploration elements on the left. This architecture development process will provide ongoing context as the elements move through implementation and execution.

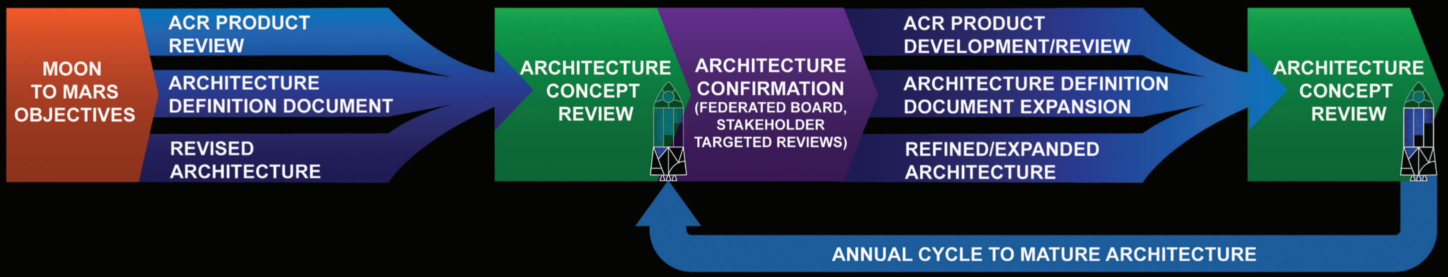
The Moon to Mars systems engineering approach decomposes the blueprint goals and objectives into characteristics and needs necessary to satisfy them. Characteristics and needs are the features and capabilities that the architecture must supply to accomplish the objectives. Using this decomposition, an architecture can be established that is capable of providing those features and activities. This process ensures a cohesive and coherent architecture can be created to achieve the blueprint goals and objectives, and ultimately the blueprint vision.



Strategic Analysis Cycles & Architecture Documentation

Architectural development will include near-constant interaction between the current state of execution and future goals and desired outcome. This interchange will foster technology infusion, innovation, and partnerships as vital to the progression of the Moon to Mars endeavor as it unfolds toward the greater blueprint vision. The Exploration Systems Development Mission Directorate will conduct strategic, iterative review of the blueprint architecture through Strategic Analysis Cycles (SAC), which will occur annually with the goal of prioritizing the work and studies needed to address open questions, coordinate with industry and international partners, and identify and resolve gaps in the architecture to achieve progress.

Documentation produced during these cycles includes the Architecture Definition Document (ADD), which will capture the most current objectives decomposition and the architecture implementation that supports it. This product will identify how the architectural elements (and their systems, subsystems, etc.) map to the characteristics and needs. The ADD also identifies gaps in the ability to satisfy blueprint objectives. Gaps can be assessed both internally by NASA and externally by stakeholders for opportunities to address in subsequent blueprint architecture and documentation iterations. As review cycles conclude, white papers and supplemental communications will capture results of the assessments (and their rationale) as solutions are implemented. Once complete, the iterative SAC effort will be reviewed at annual NASA internal Architecture Concept Reviews (ACRs).



The architectural wireframe must be constantly reviewed to ensure prioritization, address open questions, coordinate with partners, and identify and resolve gaps in the blueprint architecture to achieve progress.

Architecture Concept Reviews

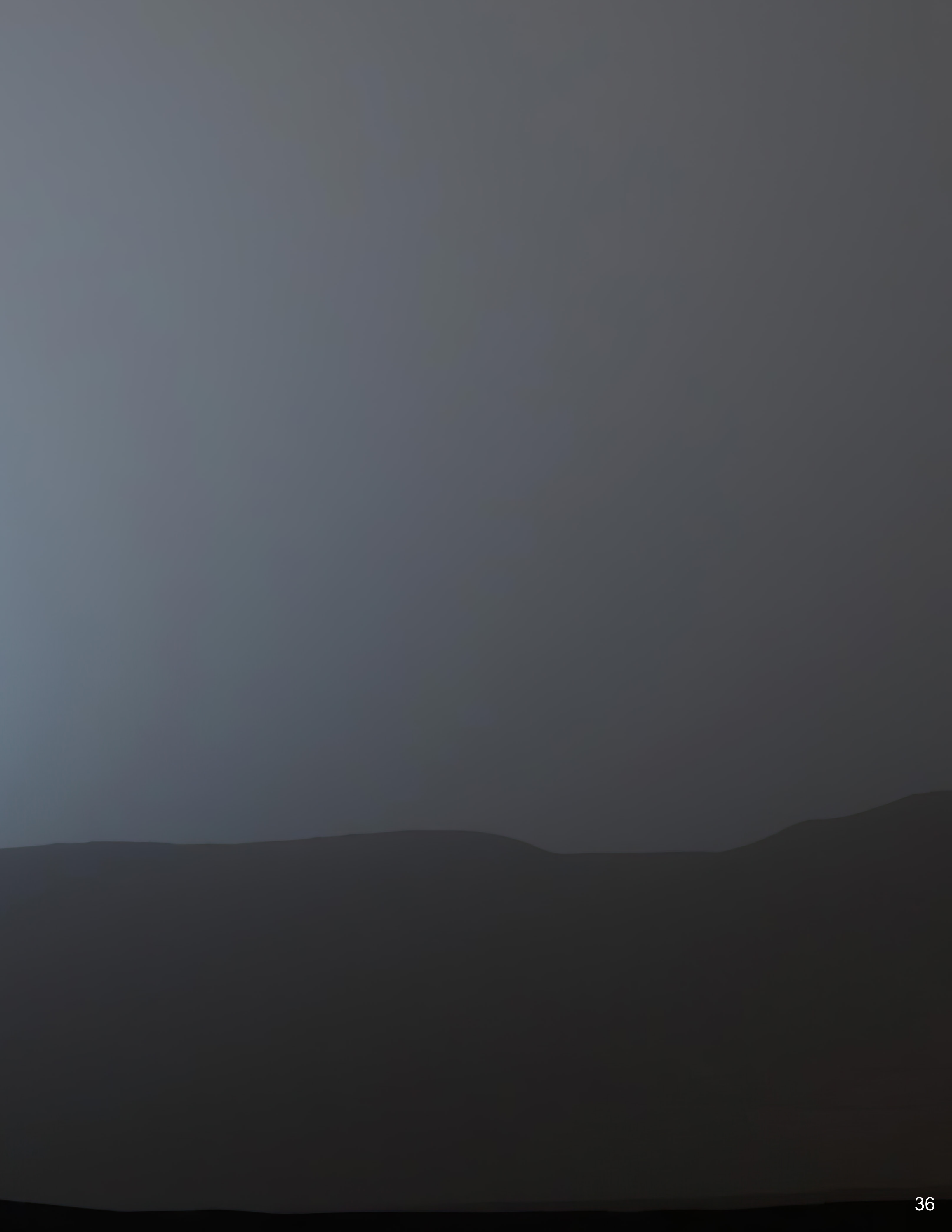
The cornerstone activity of the yearly blueprint architecture process is NASA's internal ACR. These reviews provide an opportunity to align the agency and ensure transparent communication. The annual nature of the process provides the opportunity to incorporate new developments in technologies and new industry, international, academic, or other partnerships into the architecture. Further, ACRs will be scheduled to support the yearly budget planning process by enabling analysis and understanding of architectural updates and changes in advance. Following ACR events, results will be reviewed with agency leadership and shared externally through updated ADD publication and associated supplemental products. This cadence of review and communication will document the architecture as it evolves to provide historic context and traceability for future leaders and stakeholders. The iterative approach ensures ongoing attention to constancy of purpose, thereby supporting a multi-decadal endeavor for human exploration of the Moon, Mars, and beyond.

Federated Board Targeted Reviews

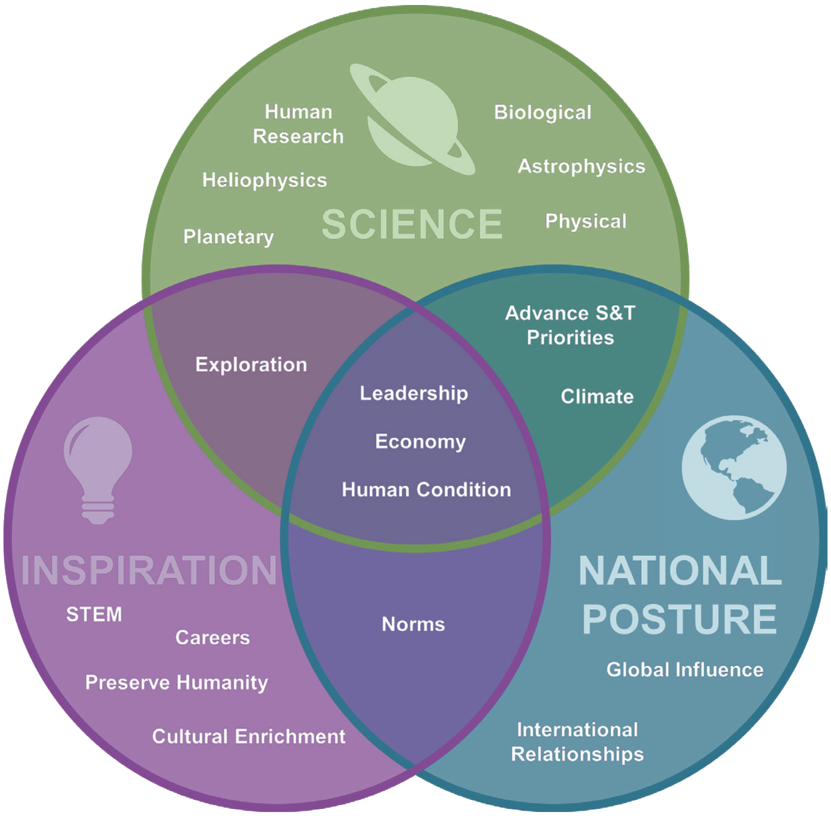
NASA's Federated Board ensures that agency priorities and general architectural direction are tightly and efficiently integrated for the Moon to Mars endeavor. To this end, the Federated Board – in coordination with auxiliary members from NASA Centers, Tech Authorities, and other key offices – conducts targeted reviews, deep dives, and periodic gap analyses of the Moon to Mars architecture. These reviews help drive consensus, promote efficient conflict resolution, help clarify strategic guidance and expectations from NASA leadership, and provide advice to the mission directorates and NASA's Executive Council.

The initial task of crafting, reaching consensus on, and refining the top-level objectives presented in this document fell to the Federated Board members. As the processes outlined in this section move forward, the Federated Board will continue to support the Exploration Systems Development Mission Directorate's development of the architecture with its reviews and will continue to refine its own processes. The Federated Board provides a high-level coordination path to address concerns prior to elevation at the Executive Council for approval. This strategic process has been established to ensure NASA and the wider stakeholder community can accomplish the ambitious endeavor that is human exploration of the Moon, Mars, and the enduring cosmos.

Sunset on Mars captured by NASA's Curiosity rover from Gale Crater on April 15, 2015. The blue tint is caused by fine particles contained in the dust in the Martian atmosphere. Credit: NASA/JPL



APPENDIX A: *WHY GO?* BENEFIT DESCRIPTIONS



Science

Human Research

"Understanding ourselves"

Exposure of humans and non-human biological systems to the environments in and around extraterrestrial bodies (beyond the Earth and the International Space Station) are critical to investigating and understanding how living systems respond and adapt to the hazards of spaceflight. These findings are fundamental to a sustained human presence in our solar system and maintaining high levels of human performance, health, and safety amidst the stress and strain of the space environment in general, and specifically, in the journeys to and time spent exploring the Moon and Mars.

Heliophysics

"New vantage points"

Observing the space environment from the Moon and Mars allows for measurements of the solar wind not possible from Earth. These measurements are fundamental in unlocking our understanding of the nature of the Sun and the dynamic processes of space weather and its influence on life on Earth.

Planetary Science

"Discoveries about geologic history"

Strategic science and sampling campaigns by crewed missions enable new insights into planetary evolution, bombardment history of the inner solar system, and prebiotic chemistry leading to new theories on habitable biospheres and the search for life in our solar system. Also, comparative planetary science helps to better understand our home planet, the Earth, and its past, present, and future.

Biological Science

"Understanding life away from Earth"

Missions to the Moon, Mars, and deep space provide scientifically transformative opportunities to conduct integrated systems biology studies using models of human physiology and crop plants. These investigations will address the underlying physiological, biochemical, and molecular mechanisms that are essential to understanding the biological responses and adaptation to these new environments.

Astrophysics

"Radio quiet measurements"

The radio quiet far side of the Moon is a unique location to take sensitive measurements of the dark ages of the universe.

Physical Science

"Understanding physical systems and processes in new environments"

The unique environments in deep space, on the Moon, and on Mars enable investigations across physical science disciplines that reveal how physical systems and processes are influenced by partial gravity, radiation, and the operational environment. These are key studies to improve our understanding of basic processes such as delivery of prebiotic materials to planetary surfaces. These studies will help define risks and hazards to allow for development of safety countermeasures to support humans, and provide foundational knowledge to enable technologies such as manufacturing in space and on the surface of the Moon and Mars, deep space propulsion, and in-situ resource utilization.

Inspiration

Science, Technology, Engineering, and Mathematics (STEM)

"Inspiring the workforce of tomorrow"

Educating the next generation starts with capturing their interest and generating excitement. Human space exploration inspires young people to pursue the education required to be productive in science and engineering fields to advance exploration into a new frontier.

Careers

"Work that makes an impact on humanity"

Opportunities to work on projects that support space exploration inspire people around the world and simultaneously expand the realm of possibility in aeronautics, astronautics, science, and technology. Astronauts, as well as scientists and engineers, and experts in information technology, human resources, accounting, law, communications, international relations, and policy – along with many other fields – must work together to break barriers and achieve audacious goals.

Preserve Humanity

"Thriving away from Earth"

The Moon to Mars enterprise lays the foundation to expand human presence into deep space and develops the ability to keep humans healthy and productive in space for longer than ever before. Living and working in isolated locations in the most extreme extraterrestrial environments will teach humanity how to survive and even thrive without Earth's support.

Cultural Enrichment

"New perspectives spark creativity and drive innovation"

New perspectives gained from exploration of the Moon and Mars and greater understanding of humanity's place in the solar system increase appreciation of the world. These new perspectives encourage engagement in the kinds of reflective, analytic, and participatory activities that enrich and deepen humanity's relationship to the world and each other.

National Posture

Global Influence

"Championing the future"

Space exploration provides opportunities to lead in the advancement of the human condition and also promotes national pride and status by contributing to a global endeavor benefitting humankind. By leading or participating in the Moon to Mars effort, a nation gains prestige and influence on the world stage. The Moon to Mars endeavor provides opportunities for a nation to make significant, unique, and historical advancements in science and technology.

International Relationships

"Opportunities to share and compound benefits among friends"

Space exploration has broad international appeal and serves as a source of worldwide inspiration. The potential for space exploration achievement is improved when nations partner to share resources, distribute responsibilities, create resilience, and promote diverse technical solutions. Collaboration in space exploration can build bridges among nations, fostering strong and enduring relationships. A nation may choose to participate in the Moon to Mars endeavor to advance its own domestic priorities while enriching its international partnerships, which can yield stronger relationships in many dimensions: political, financial, and social.

Intersection of Science and Inspiration

Exploration

"Satisfying humanity's need to expand understanding of our place in the universe"

Exploration and the quest for knowledge have always motivated human activity. Whether at the personal level or the societal level, the desire to explore and understand the world has expanded the limits of human civilization. At the individual level, curiosity leads to career pursuits, new technology development, the creation of works of art and entertainment, and much more. The result is a sense of individual fulfillment and inspiration gained through deeper understanding and increased ability to shape individual existence. At the societal level, great enterprises – such as grand exploration endeavors – improve the world for future generations. As a gift from people of the past and present to those of the future, exploration inspires NASA's Moon to Mars endeavor.

Intersection of Science and National Posture

Advance Science and Technology Priorities

“Enabling the future through science and technology development”

Advances in science and technology that lead to new knowledge and its application are instrumental to enabling future programs and capabilities. Pushing the boundaries of science and technology expands and improves capabilities – and not just in the space sector. Grand challenges like the Moon to Mars endeavor drive advancements across a wide range of disciplines, with spinoff benefits often expanding to areas of society well beyond their initial application. In doing so, these advances improve the standard of living, expand the economy, and provide future security.

Climate

“Understanding other worlds to safeguard our own”

Studying the Moon, Mars and other deep space destinations informs about the history of the solar system and the Earth. Understanding the geological and climate histories of Mars and Venus, Earth’s nearest neighbors, has already significantly informed potential development paths of rocky planets such as Earth. Studying these and other places in even more detail will deepen understanding of the Earth’s climate processes, and how to address humanity’s impact on them. Exploration can lead to spinoff technologies and discoveries that could help predict and prepare to mitigate the effects of climate change.

Intersection of Inspiration and National Posture

Norms

“Be the example; influence the rules of the road”

History is replete with examples of leading nations having the opportunity to set the practices for those that follow: air traffic management, maritime rules, frequency management in the geosynchronous Earth orbit belt, etc. Through exploration of the Moon, Mars, and other bodies, NASA and its partners create the rules of engagement that best serve their citizens, including norms for operational activities and advanced demonstrations of science and technology to shape the safe and sustainable use of space.

Intersection of Science, Inspiration, and National Posture

Leadership

“Leading the way to a human future in space”

Leadership means setting the example, maximizing effort towards achievement, and inspiring others to do the same, even when the task is challenging. History shows that strong leadership provides vision and encouragement resulting in the growth of people and society as well as inspiration to achieve what was previously thought impossible. Much like previous milestones with Apollo, the Space Shuttle Program, and the International Space Station, NASA’s leadership of the science and technical capabilities needed to achieve the Moon to Mars objectives will inspire millions in the United States and throughout the world, improve national posture for those who participate in the effort, and spur the advancement of science for the benefit of all.

Economy

"Creating a sustainable ecosystem for innovation, exploration, and public benefit"

Economic opportunity has followed and supported humanity in its global expansion, throughout history. Likewise, trade will be essential to humanity's early steps into the solar system. The Moon and Mars are the most remote, hostile, and difficult environments humans will have ever visited, even in comparison to the most extreme Earth environments, such as Antarctica. Like today's Antarctic research bases and the International Space Station, early human efforts on the Moon and Mars will rely on a network of commercial, international, and other partners working together to support NASA's efforts. Over time, through the development of innovative new technologies and operations adapted to these extreme environments, these early efforts will pave the way toward more capable, sustainable, and increasingly Earth-independent operations. These contributions will come from a variety of participants, with the potential to unlock benefits for all of humanity.

Human Condition

"Exploring space for the benefit of humanity"

Improvement of the human condition is at the heart of NASA's work and the aims of the Moon to Mars endeavor. Being at the center of the Venn diagram, the human condition is tied to all other benefits of strategy, and in turn, those benefits' influence on the human condition.

When people are inspired in their lives by NASA's activities through career pursuits or the knowledge gained, the human condition improves. The human condition is likewise strengthened by the improvement of national posture through cohesiveness in space exploration activities. Improved scientific knowledge can influence action on climate, biological and human research, and applications of astrophysics and heliophysics to understanding the universe, humanity's place in it, and the impact that the space environment has on the Earth and the lives on it.

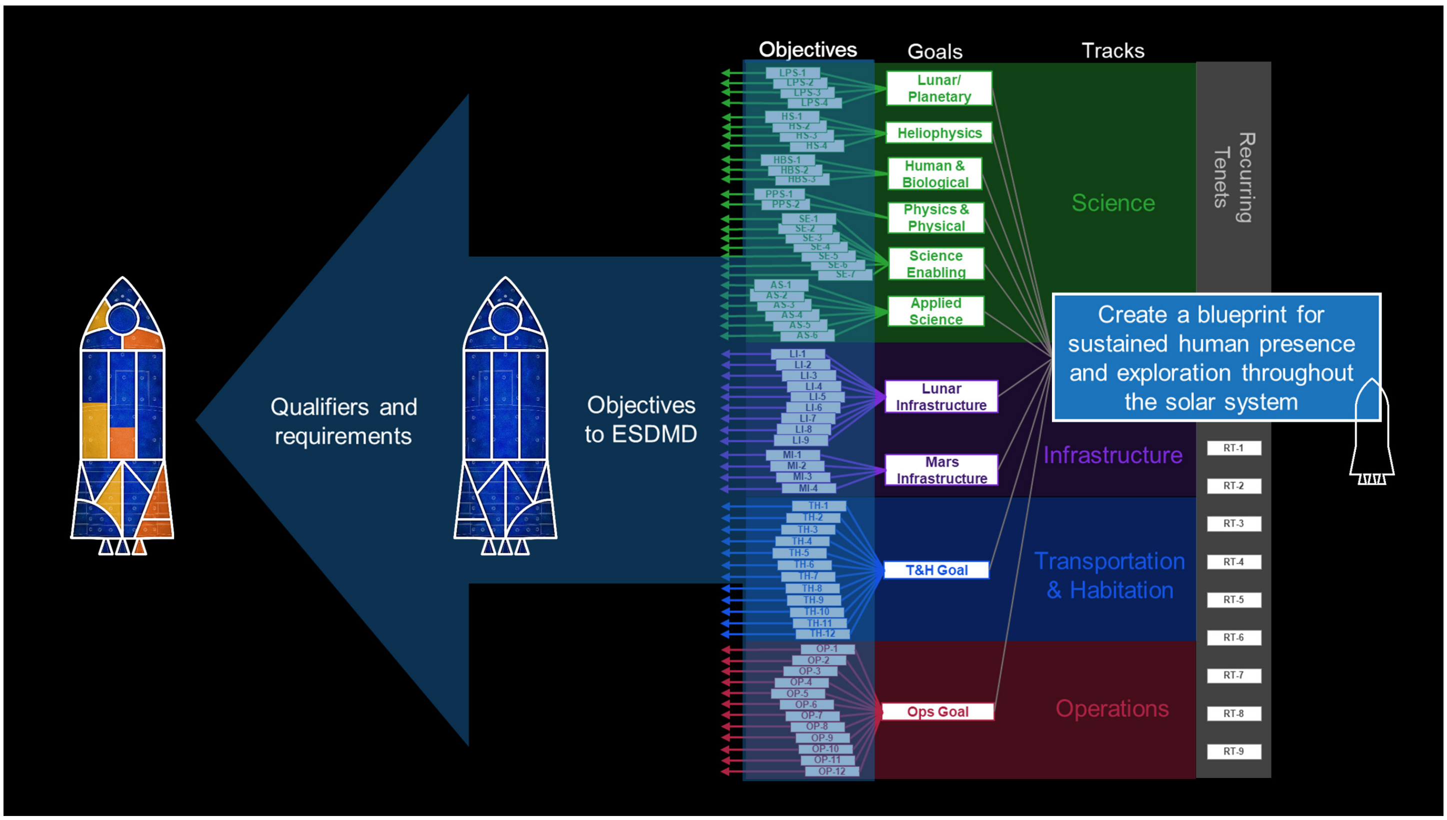
Leadership, Economy, and Human Condition are inextricably intertwined at the center. Demonstrated and sustained leadership through challenging efforts like Moon to Mars positively reflects the society pursuing the effort. Without people and society, the economy wouldn't exist. Likewise, without healthy, capable, and motivated people exchanging goods, services, and opportunities through a robust and fair economy, society would suffer. Expanding human activity into space in a way that allows as many people as possible to participate, contribute, and benefit significantly improves the human condition.

APPENDIX B: OBJECTIVES DEVELOPMENT PROCESS

In accordance with the methodology principle of Architect from the Right, in November 2021, the NASA Executive Council tasked the mission directorates to draft a set of top-level goals and objectives necessary to achieve the Moon to Mars endeavor. The task would use Federated Board processes to reach consensus.

The top-level goals and objectives were binned into four distinct tracks:

- **Science**
- **Infrastructure**
- **Transportation and Habitation**
- **Operations**

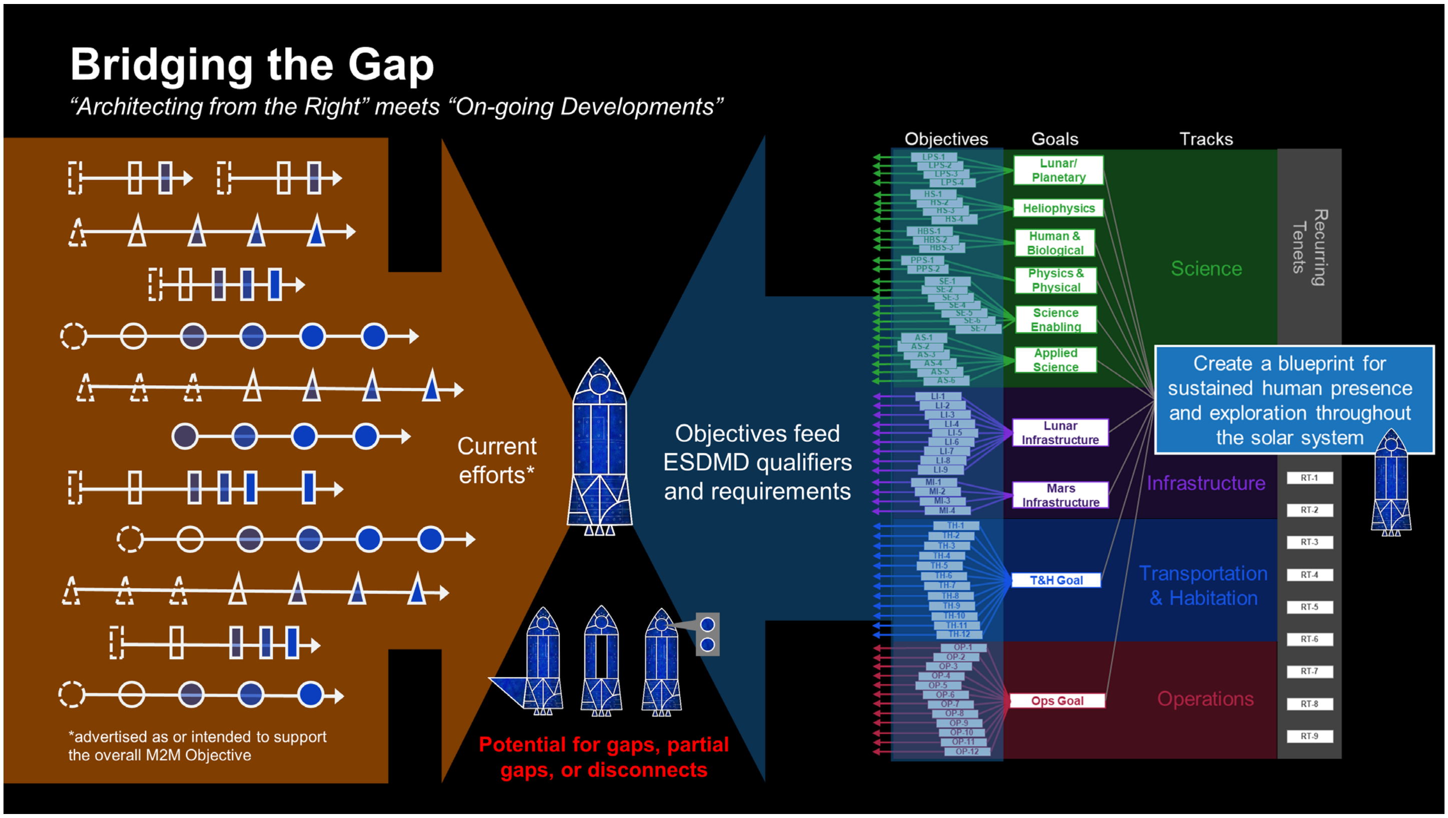


A graphical depiction of how goals and objectives were developed with an eye toward the blueprint vision, and how they work together to achieve that vision. With goals and objectives developed, the architecture will follow.

Each of the mission directorate leaders on the Federated Board led the development of corresponding objectives: **Science** was led by the Science Mission Directorate; **Infrastructure** was led by the Space Technology Mission Directorate; **Transportation and Habitation** was led by the Exploration Systems Development Mission Directorate; and **Operations** was led by the Space Operations Mission Directorate. The Aeronautics Mission Directorate supported the Science Mission Directorate with the Science objectives and was actively involved in the entire objectives development process. The Federated Board reached consensus on an initial draft set of 45 objectives by March 2022.

Gap Analysis

While leadership began the process of Architecting from the Right, NASA recognized the need to bridge the gap between current efforts and the new strategy. In April 2022, the Federated Board began a comprehensive gap analysis to assess the draft objectives against current and planned Moon to Mars activities. The gap analysis acted as an early assessment of NASA's current architecture while simultaneously serving to refine the draft objectives by identifying gaps, disconnects, and disagreements between current efforts and desired future state. It cross-analyzes the objectives through the lens of current efforts, and current efforts through the lens of the objectives.



Ongoing efforts must merge with strategy toward future state; the gap analysis bridges this gap.

The gap analysis involved a phased evaluation of the initial 45 draft objectives, starting with self-assessments by each mission directorate, followed by an agency-level cross-assessment. These examinations were aggregated into findings that identified missing activities that would need to be addressed, correlated current and planned efforts to the new strategy, and informed next steps in the process. The findings also spurred dedicated discussions to better understand and identify complex, interrelated issues that surfaced.

In total, 12 objectives gaps arose, leading to the addition of five new objectives, one new overarching principle, six edits to existing objectives, and one edit to an existing goal. Objectives also received new/revised language for added clarity. These changes appeared in the May 2022 release of 50 draft objectives.

Feedback Campaigns and Workshops

The May 2022 release of the 50 draft objectives kicked off a feedback campaign soliciting input and jumpstarting communication and engagement. In parallel with the draft objectives release, NASA released a supporting video that overviewed the ongoing strategy development, the objectives development process, and the architecture planning process. It featured Deputy Administrator Pam Melroy, Director of Space Architecture Spuds Vogel, and Associate Administrator of the Exploration Systems Development Mission Directorate Jim Free.

In May 2022, the opportunity for the NASA workforce to engage began via a NASA@Work campaign. The campaign enabled the workforce to discuss and elevate thoughts and ideas relating to the objectives in a moderated online forum. This engagement garnered 151 distinct ideas and 43 comments ranging from specific feedback on the objectives themselves to technical solutions to implement, suggestions of technologies that can aid exploration missions, and ideas for how to message and communicate NASA's work in the Moon to Mars endeavor. These comments and inputs were first reviewed by the Federated Board Executive Secretariat for relevance, followed by subject matter expert review by teams from each mission directorate. Inputs were due in early June 2022 and review was completed by end of June 2022.

At the same time, an online public feedback campaign provided anyone from anywhere on the globe the opportunity to comment on each of the 50 draft objectives and to provide additional comments not associated with a single objective. The feedback form was open for the month of May 2022, and captured 902 separate submissions. These submissions included more than 5,000 total comments. As with the NASA@Work inputs, these comments were first reviewed by the Federated Board Executive Secretariat followed by a subject matter expert review by teams from each mission directorate.

The 902 public responses were from a wide variety of sources, ranging from the international public and academia, U.S. aerospace advocacy groups, and U.S. industry. Following review of the comments, each mission directorate selected responses warranting further conversation which, for the public, was accomplished in the form of one-on-one follow-ups. Further engagement with respondents from academia, industry, and space advocacy organizations occurred in an in-person workshop held in June 2022 at Space Center Houston. Of 40 invited, 30 organizations attended. The workshop was structured such that attendees could engage directly, candidly, and privately with subject matter experts from the mission directorates corresponding to the four tracks. **During this workshop, industry raised the need for architectural consistency to guide investments, along with the need for a signal from NASA that it would be the anchor tenant for services that industry would provide.**

To engage international partners, NASA led a Moon to Mars objectives workshop in July 2022, hosted by the United Kingdom Space Agency (UKSA) at the Royal Institute in London. Sixteen international space agencies participated in the two-day summit. Again, attendees could engage directly with mission directorate subject matter experts corresponding to the four tracks through open dialogs involving all attending space agencies. **The resulting conversations raised a key question beyond the objectives: how can space agencies partner with NASA?**

In September 2022, the Federated Board convened with NASA field center and Jet Propulsion Laboratory leadership teams to provide additional, unique perspectives in the objectives development process. **Resulting feedback primarily represented Center roles and priorities, and additionally suggested more thoroughly defining the overarching "why" behind the objectives. Center leadership showed interest in how the goals and objectives will be used to drive difficult blueprint architecture decisions.**

Key themes emerged across the immense database of stakeholder inputs, some of which included:

- Lunar science objectives were too broad and Mars-specific science was absent.
- Ensure that objectives have a feed forward to desired activities on Mars and destinations beyond.
- There is high interest in regular industry and international communication and collaboration.
- Define interoperability standards early on, perhaps with dedicated objectives.

Summer Scrub

The inputs from these feedback streams were then synthesized in an activity dubbed the "summer scrub" to update and polish the Moon to Mars objectives and strategy features. As part of the feedback review, several format and overarching updates to the objectives documentation were implemented, including:

- Establish a single, concise statement that summarizes the process and the end state that the objectives enable: "Define the overarching Moon to Mars objectives for NASA to drive its architecture, plans, and efforts in enabling sustained human presence and exploration throughout the solar system."
- Document the methodology principals for reference, to ensure consistency of communications.
- Rename the Overarching Objectives Principals to Recurring Tenets, which were expanded from four to nine.
- Re-order objectives tracks: Recurring Tenets, Science, Infrastructure, Transportation and Habitation, Operations.
- Add rationale statements for the objectives tracks to provide context.
- Change nomenclature from "Mars demonstration mission" to "Mars Initial Campaign"
- Call out Lunar and Mars related objectives consistently across tracks and combine where appropriate to show linkages by using superscript L, M, or LM.

Each mission directorate led the review of and updates to its corresponding track of objectives. The summer scrub resulted in an increase from nine to 10 goals, with a restructure of the science goals. The number of objectives increased from 50 to 63, across the 10 goals. They are distributed across tracks as follows.

- **Science:** Six goals with 26 objectives
- **Infrastructure:** Two goals with 13 objectives
- **Transportation and Habitation:** One goal with 12 objectives
- **Operations:** One goal with 12 objectives

Objectives Rollout

In keeping with the methodology principal of enhanced communication and engagement, stakeholders – including the Executive Office of the President and Congress and the International Space Agency – received a summary of changes and a copy of the updated objectives prior to public release. The revised objectives were officially released at the International Astronautical Congress in Paris, France in September 2022. Since then, internal and external Town Halls and briefings have continued with the purpose of increasing knowledgeability and inclusion of stakeholders.

APPENDIX C: MAPPING SCIENCE GOALS AND OBJECTIVES TO DECADAL SURVEYS

NASA prioritizes science investigations based on recommendations laid out in community documents and/or internal roadmaps. The Science Mission Directorate (SMD) regularly engages with the National Academies of Sciences, Engineering, and Medicine (NASEM) to produce decadal research studies that are the basis for recommendations of top-priority science areas for NASA investments in the upcoming decade. Each division of NASA's SMD engages the NASEM in this decadal survey process that outlines priority missions and research strategy, and identifies areas of high value science investigation. Additionally, the Space Operations Mission Directorate's Human Research Program maintains the Integrated Research Plan that describes the research and technology development activities required to mitigate risks to human space explorers. The science-focused Moon to Mars objectives trace back to these guiding documents as outlined in Table C.1 below.

Current guiding documents:

Planetary Science: Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (2022)

Heliophysics: Solar and Space Physics: A Science for a Technological Society (2013) (to be updated in 2023)

Astrophysics: Pathways to Discovery in Astronomy and Astrophysics for the 2020s (2021)

Biological and Physical Sciences: Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era (2011) (to be updated in 2023)

Human Research: Integrated Research Plan (2022)

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-1LM: Uncover the record of Solar System origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner Solar System as recorded on the Moon and Mars, and characterize how impact rates in the inner Solar System have changed over time as recorded on the Moon and Mars.	Q2: Accretion in the Outer Solar System: How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the Solar System?	Q2.4 How did the giant planets gravitationally interact with each other, the protosolar disk, and smaller bodies in the outer Solar System?
	Q3. Origin of Earth and inner solar system bodies. How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer solar system materials incorporated?	Q3.1 How/when did asteroids and inner Solar System protoplanets form?
		Q3.2 Did giant planet formation and migration shape the formation of the inner Solar System?
		Q3.3 How did the Earth/Moon system form?
		Q3.4 What processes the unique initial state of Mars?
		Q3.5 How and when did the terrestrial planets and Moon differentiate?
	Q4. Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?	Q4.1 How have planetary bodies collisionally and dynamically evolved throughout Solar System history?

2023 Decadal Strategic Research
Determine the timing, extent and effects of giant planet migration by measurement of impact basin ages on the terrestrial planets, compositional and isotopic constraints on early terrestrial planet evolution, including the origin of the Moon, and studies of impact crater populations on diverse outer Solar System bodies
Determine the compositional diversity of the terrestrial planets and inner solar system feedstocks by obtaining mineralogical, geochemical, and isotopic data from the surfaces and atmospheres of Mercury, Venus, Moon, and the less explored regions of the Moon and Mars, as well as the currently unsampled small body population.
Evaluate the nature of early projectiles that struck the terrestrial planets and the Moon by analyzing regolith samples likely to contain remnant clasts from early bombardment impactors and by obtaining isotopic traces of projectile materials from lunar craters and basins.
Determine the timing of the giant planet instability through evidence of early comet bombardment of the asteroid belt (e.g., impact history of large asteroids that resisted disruption, identification of common shattering/disruption times for asteroids from meteorite shock degassing ages) and constraining the ages of the oldest lunar impact basins.
Constrain the physical and chemical characteristics of Theia and the proto-Earth through sample analysis or in-situ isotopic measurements of inner solar system bodies (particularly Venus or Mercury), as well as improved models to explain the isotopic and geochemical constraints of Earth and the Moon.
Determine the timing of the Moon-forming giant impact and solidification of LMO by isotopic analysis of lunar rocks from nearside and farside of the Moon and by refining theoretical models to estimate the timescale for the duration of LMO crystallization.
Seek evidence for post-giant impact equilibrium between Earth and Moon by analyzing terrestrial and lunar samples for stable refractory element isotopic compositions
Differentiate between giant impact concepts by developing model predictions for observable properties of the Moon and Earth and comparing them with lunar compositional and geophysical data.
Determine the origin of the Martian moons by comparing chemical and isotopic ratios of Mars, Phobos, Deimos and asteroids and constraining their interior structures.
Determine the formation time of Mars through isotopic analyses of diverse Martian samples
Determine the age relations between the oldest lunar crustal and mantle rocks by dating lunar crustal and mantle rocks, which may be potentially found at the South-Pole Aitken basin.
Determine the age and duration of primordial differentiation on Earth, Moon and Mars through isotopic analysis of samples collected from new locations on Moon and Mars, and through thermal modeling.
Determine and compare the mechanisms of differentiation, size of body, and location of bodies in the solar system through sample analysis, spacecraft observation, and geochemical/geophysical modeling
Assess the contribution and effects of late accretion on the post-differentiation inner planets by analysis of ancient terrestrial materials, samples from regions of Mars and the Moon likely to be derived from each world's mantle
Determine the nature of impactors striking the most ancient regions of the Moon in order to constrain early bombardment populations by returning samples of soils/breccias from lunar farside regions where ancient materials have been recently excavated by impacts.
Constrain the early impact populations striking Mars by identifying the oldest basins and impact structures (including basins that have been potentially erased by other geologic processes) and determining their age.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-1^{LM}: Uncover the record of Solar System origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner Solar System as recorded on the Moon and Mars, and characterize how impact rates in the inner Solar System have changed over time as recorded on the Moon and Mars.	*Q4. Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?*	Q4.2 How did impact bombardment vary with time and location in the Solar System?
		Q4.4 How do the physics and mechanics of impact produce disruption of and cratering on planetary bodies?
	Q5. Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?	Q5.2 How have the interiors of solid bodies evolved?
		Q5.3 How have surface/near-surface characteristics and compositions of solid bodies been modified by, and recorded, interior processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?	Q6.1 How do solid-body atmospheres form and what was their state during and shortly after accretion?
	Q9. What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?	Q9.1 What were the conditions and processes conducive to the origin and early evolution of life on Earth, and what do they teach us about the possible emergence and evolution of life on other worlds?

2023 Decadal Strategic Research
Determine the age of the South Pole-Aitken (SPA) basin to determine the beginning of recorded bombardment on the ancient lunar far side by dating samples formed from or excavated by the SPA basin forming event.
Determine a precise absolute chronology for lunar impactors that can be applied to other worlds by measuring radiometric ages for terrains likely to be much older than 3.9 Gyr and younger than 3 Gyr, counting superposed small craters on D > 10 km craters, and calculating model ages for those craters.
Determine the absolute age of a Martian basin or well-defined surface and use it to calibrate the timing of early Martian bombardment by dating a surface whose age can be determined by in-situ methods or returned samples.
Determine the formation of the South Pole Aitken (SPA) basin's asymmetric structure by characterizing the chemical compositions and geologic structures (e.g., shock fragmentation, etc) of the surface and internal materials returned near or within SPA and by constraining the internal structure beneath SPA
Determine crustal composition, heat production, and origin of crustal dichotomies (if any) on the Moon, Mars and Venus by in-situ geochemical, mineralogical and heat flow measurements by rover(s) or lander(s), by laboratory analyses of returned samples, and by collecting orbital and seismic data.
Determine the temperature, depth and timing of chemical differentiation, and the compositional and petrologic characteristics of magmas on different bodies by a combination of theoretical and experimental studies on samples or analog compositions.
Assess the diverse mechanisms that create magnetic fields by measuring the topology and evolution of active geodynamos in Mercury and Ganymede, determining whether Venus had an active geodynamo, and by studying remanent crust magnetization produced by extinct dynamos on the Moon and Mars, via spacecraft measurements or paleomagnetic studies of returned samples
Identify and classify tectonic and volcanic landforms (both modern and ancient) on rocky bodies (Venus, Mars, Mercury, the Moon, and Io), and provide fundamental constraints on lithospheric properties such as the thickness of the deforming layer via high-resolution topography, gravity and images of the surfaces, and chemical and mineralogical measurements.
Improve understanding of the initial states of planetary atmospheres by developing coupled models of magma oceans coupled to processes such as delivery, loss of volatiles from impacts, chemistry, dynamics, and atmospheric escape due to both thermal and non-thermal escape mechanisms.
Develop physical and chemical constraints on early atmosphere-interior exchange by performing laboratory experiments on volatile partitioning in silicate melts, meteorite shock chemistry, and related phenomena.
Characterize the surface and subsurface processes (e.g., impactor flux, atmospheric conditions, volcanism, tectonism) and the range of chemical inventories (e.g., volatiles, organics) present during the emergence of Earth's nascent biosphere through modeling, analyses and measurements of solar system materials (asteroids, comets, interplanetary dust particles, and meteorites), investigation of Earth's isotopic record, and estimation of fluxes recorded and volatiles deposited on ancient, well preserved inner solar system planetary surfaces (Moon and Mercury).
Characterize how the early, dynamic solar system environment shaped Earth's environments and the subsequent emergence and evolution of life therein by determining a reliable absolute chronologic record of the early bombardment of the Earth-Moon system, especially prior to 3.7 Ga.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-2^{LM}: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/ exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	Q3. Origin of Earth and inner solar system bodies. How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer solar system materials incorporated?	Q3.3 How did the Earth/Moon system form?
		Q3.5 How and when did the terrestrial planets and Moon differentiate?
		Q3.6 What established the primordial inventories of volatile elements and compounds in the inner Solar System?
	Q4. Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?	Q4.1 How have planetary bodies collisionally and dynamically evolved throughout Solar System history?
		Q4.2 How did impact bombardment vary with time and location in the Solar System?
		Q4.3 How did collisions affect the geological, geophysical, and geochemical evolution and properties of planetary bodies?
		Q4.4 How do the physics and mechanics of impact produce disruption of and cratering on planetary bodies?
	Q5. Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?	Q5.1 How diverse are the compositions and internal structures within and among solid bodies?
		Q5.2 How have the interiors of solid bodies evolved?

2023 Decadal Strategic Research
Determine the internal structure of the Moon with sufficient resolution to constrain its bulk composition and initial thermal state using geophysical measurements obtained from spacecraft and/or a seismic network and other in-situ analyses.
Determine the Moon's interior composition by sample return and/or in-situ analysis of materials that reflect the Moon's endogenic composition at depth, e.g., glass beads, primitive basalts, and/or exposed lunar mantle.
Determine the oxidation state of planetary surfaces to understand the primary drivers of redox conditions with spacecraft observations and sample analysis.
Precisely determine the elemental and isotopic compositions of Martian mantle and atmospheric volatiles at present and in the past by analyzing carefully selected atmospheric and solid samples with different ages and provenances returned from Mars.
Determine how meteoroid bombardment can alter the surfaces and potentially produce exospheres on airless worlds by characterizing dust populations across the solar system and determining their impact effects through laboratory studies, observations, and numerical experiments.
Determine the present-day lunar impact rate and better understand the nature of impact mechanics by coupling seismic monitoring to lunar observations of impact flashes and fresh impact craters.
Determine impactor sizes, impactor compositions, and impact ages for all terrestrial impact structures by identifying and characterizing past impact structures, analyzing samples that contain telltale traces of the projectile, and dating material affected by the impact event.
Determine the composition and depth of the materials, possibly lunar mantle, excavated by the South Pole-Aitken (SPA) basin formation by returning samples from near or within the basin with the characteristics of the deep interior.
Determine how impact physics and mechanics changes at different impact sites by mapping those sites with high-resolution remote sensing images, identifying target material compositions using in-situ and/or remote methods, and applying the information as constraints for numerical impact simulations.
Determine how impacts affect oceans and ices on Mars by characterizing Martian surface conditions (i.e., geologic and chemical compositions, and the existence of water or ice) through time and then by simulating impacts into such target materials.
Probe the internal structures of the Moon, Mars, and Mercury by establishing a geophysical (seismic/magnetometer) network on the former two bodies and making the first surface seismic/magnetometer measurements on the latter.
Determine stable mineral assemblages and the pressure-temperature conditions of melt generation in the interiors of Moon, Mars, Venus, Mercury, Io and other rocky worlds by carrying out laboratory experiments on returned samples, meteorites and analog compositions under relevant conditions.
Determine the timing and flux of volcanism on Venus, Mars, and Mercury using orbital and in-situ measurements of crustal composition and mineralogy with accompanying in-situ radiometric dating.
Probe the magmatic history of the Moon by conducting coordinated high-fidelity geochronology, geochemistry, and petrologic analyses either by in-situ exploration or by analyzing samples returned by robotic or crewed missions.
Determine crustal composition, heat production, and origin of crustal dichotomies (if any) on the Moon, Mars and Venus by in-situ geochemical, mineralogical and heat flow measurements by rover(s) or lander(s), by laboratory analyses of returned samples, and by collecting orbital and seismic data.
Determine the temperature, depth and timing of chemical differentiation, and the compositional and petrologic characteristics of magmas on different bodies by a combination of theoretical and experimental studies on samples or analog compositions.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-2[LM]: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/ exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	*Q5. Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?*	*Q5.2 How have the interiors of solid bodies evolved?*
		Q5.3 How have surface/near-surface characteristics and compositions of solid bodies been modified by, and recorded, interior processes?
		Q5.4 How have surface characteristics and compositions of solid bodies been modified by, and recorded, surface processes and atmospheric interactions?
		Q5.5 How have surface characteristics and compositions of solid bodies been modified by, and recorded, external processes?
		Q5.6 What drives active processes occurring in the interiors and on the surfaces of solid bodies?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?	Q6.1 How do solid-body atmospheres form and what was their state during and shortly after accretion?
		Q6.2 What processes govern the evolution of planetary atmospheres and climates over geologic timescales?

2023 Decadal Strategic Research
Assess the diverse mechanisms that create magnetic fields by measuring the topology and evolution of active geodynamos in Mercury and Ganymede, determining whether Venus had an active geodynamo, and by studying remanent crust magnetization produced by extinct dynamos on the Moon and Mars, via spacecraft measurements or paleomagnetic studies of returned samples
Identify and classify tectonic and volcanic landforms (both modern and ancient) on rocky bodies (Venus, Mars, Mercury, the Moon, and Io), and provide fundamental constraints on lithospheric properties such as the thickness of the deforming layer via high-resolution topography, gravity and images of the surfaces, and chemical and mineralogical measurements.
Determine the range of volatile contents and species in planetary melts in igneous samples from Mars, the Moon and asteroids, to constrain the range and variety in planetary volatile contents, and factors influencing melt generation, composition, and eruptibility using Earth-based laboratory measurements of returned samples and/or meteorites.
Assess the nature and timing of hydrothermal processes on small bodies and planets via modeling of aqueous alteration, and a combination of high-resolution spectral data and laboratory analyses of samples of asteroids Ryugu and Bennu returned by Huyabusa2 and OSIRIS-REx, from Mars's moon Phobos from MMX, and from Mars by the Mars Sample Return Program.
Map and measure the geologic, chemical, and mineralogical characteristics of Mars's Noachian stratigraphic record to correlate local and regional sedimentary depositional episodes and provide insight into the range and diversity of environments and their relative timing via in-situ measurements from a long-distance rover or airborne vehicle.
Characterize the paleoenvironment, weathering, habitability, geochemistry, petrology, geochronology, and geologic history of returned samples from an ancient Martian sedimentary sequence, as well as regolith and any igneous rocks, via laboratory analyses of samples returned from Mars.
Constrain weathering rates and regolith formation, including physical, chemical, and mineralogical changes to surface materials during weathering under conditions relevant for Venus, Mars, and Titan using experimental studies of abrasion, weathering reactions, and kinetics.
Investigate the role of space weathering processes on airless rocky bodies using high-resolution imaging and spectroscopy of planetary surfaces coupled with laboratory studies of representative/analog materials and laboratory analyses of returned samples.
Assess processes producing lunar regolith heterogeneity by measuring the thickness variations, and vertical and lateral compositional variability of the lunar regolith, using geophysical profiling, high-resolution multi-spectral imaging, and petrologic analyses of in-situ or returned samples.
Constrain the rate of active surface changes on Mars related to dune migration, mass movements, sedimentation, or ice sublimation using either long-term, repeat-pass high-resolution altimetry or imaging
Constrain the earliest stages of atmospheric evolution on Venus, Mars, and Titan by measuring noble gas abundances and isotopic fractionation to sufficient precision to quantify their minor isotopes.
Improve understanding of the initial states of planetary atmospheres by developing coupled models of magma oceans coupled to processes such as delivery, loss of volatiles from impacts, chemistry, dynamics, and atmospheric escape due to both thermal and non-thermal escape mechanisms.
Develop physical and chemical constraints on early atmosphere-interior exchange by performing laboratory experiments on volatile partitioning in silicate melts, meteorite shock chemistry, and related phenomena.
Constrain the timing of Martian climate transitions by performing geochronological dating of samples from multiple locations on the planet's surface.
Constrain atmospheric evolution processes on Mars by returning samples of the atmosphere to Earth of sufficient concentration and fidelity to allow noble gas abundance and isotopic fractionation to be measured.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-2[LM]: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	*Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?*	*Q6.2 What processes govern the evolution of planetary atmospheres and climates over geologic timescales?*
		Q6.3 What processes drive the dynamics and energetics of atmospheres on solid bodies?
		Q6.4 How do planetary surfaces and interiors influence and interact with their host atmospheres?
		Q6.5 What processes govern atmospheric loss to space?

2023 Decadal Strategic Research
Determine how and why Mars's climate has changed over orbital time scales by performing radar and spectroscopic mapping of the polar layered terrain and by making in-situ measurements of their structure and composition (thickness of layers, dust content, and isotope ratios) and their local meteorology (including volatile and dust fluxes).
Study surface-exchange processes across a diverse range of atmospheric compositions by developing one, two, and three-dimensional models of past and present planetary climates.
Investigate the radiative forcing potential, chemistry and microphysics of greenhouse gas, haze, and cloud combinations relevant to climate evolution processes by performing laboratory studies.
Determine how atmospheric waves drive atmospheric dynamics and energetics, especially phenomena such as supperrotation and lower-upper atmosphere coupling by observing wave amplitudes, periods, phases, and spatio-temporal distributions in thermal and direct wind measurements over multiple annual cycles on Venus, Mars, and Titan.
Determine how the surface is coupled to the main atmosphere by measuring the transport of heat, momentum, volatiles, and dust through the planetary boundary layer, via in-situ and remote sensing observations of fluxes covering key time periods or environmental conditions, on bodies with collisional atmospheres such as Venus, Mars, and Titan.
Investigate the cause of variability in Martian dust storms and hence climate by making in-situ measurements of surface dust and sand fluxes simultaneous with environmental conditions, and in-situ and orbital measurements of surface dust and sand availability.
Determine how aerosols influence atmospheric dynamics and energetics by measuring their properties and spatio-temporal distributions, simultaneous with the thermal and circulation response of the atmosphere, on diurnal, seasonal, and multi-annual timescales on Venus (clouds and hazes), Mars (dust and clouds), and/or Titan (hazes, clouds, and dust).
Determine the effectiveness of ion-neutral drag on augmenting upper atmospheric circulation by performing in-situ measurements of ion and neutral winds, as well as ion electron densities, plasma distribution functions, and magnetic fields, on Venus, Mars, and Titan.
Explore the connections between the solar wind, magnetic fields, and the neutral atmosphere/exosphere through numerical modeling.
Determine how dust lifting and sand motion are linked to the state of the near-surface atmosphere by making simultaneous, in-situ measurements of dust and sand fluxes, surface properties, and environmental conditions (e.g., winds and electric fields) at the surface of Mars, Venus, and Titan.
Test and improve theories relating dust lifting, sand motion, and aeolian feature characteristics to environmental conditions (e.g., winds, electric fields, grain sizes) on other planetary surfaces by performing laboratory, numerical, and terrestrial analog field studies.
Infer near-surface wind patterns and environmental conditions, and how they change over time, by documenting aeolian features and how they vary over seasonal and annual cycles via high-resolution imaging on Mars and Titan.
Trace the flow of energy and escaping gases through collisional atmospheres (e.g., Venus, Mars, Triton, Titan, Pluto) to diagnose lower-upper atmosphere coupling, utilizing simultaneous measurements of the lower and upper atmosphere and exosphere.
Discover how escaping ions influence the magnetospheric current systems by performing multi-point measurements in induced (e.g., Venus and Mars) and intrinsic (e.g., Mercury) magnetospheres.
Relate the loss of volatiles from surface boundary exospheres to solar wind dynamics and quantify the effects of magnetic fields by measuring escaping, migrating, and bound species in regions of different magnetic topology (e.g., Mercury and Ganymede polar and equatorial regions, lunar magnetic anomalies).
Reveal the factors that control the structure, composition, and dynamics of surface boundary exospheres (e.g., Mercury, Moon, Ceres, Europa) by simultaneously measuring energetic inputs and escaping species for at least one orbit and preferably for a substantial portion of the solar cycle.
Establish the influence of magnetic fields in constraining atmospheric loss by simulating escape from bodies with and without intrinsic and/or parent body magnetic fields with sufficient fidelity to resolve pertinent loss processes.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-2[LM]: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/ exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	*Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?*	*Q6.5 What processes govern atmospheric loss to space?*
		Q6.6 What chemical and microphysical processes govern the clouds, hazes, chemistry and trace gas composition of solid body atmospheres?
	Q8. Circumplanetary systems. What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?	Q8.1 How did circumplanetary systems form and evolve over time to yield different planetary systems?
		Q8.2 How do tides and other endogenic processes shape planetary satellites?
		Q8.3 What exogenic processes modify the surfaces of bodies in circumplanetary systems?
	Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?	Q10.2 Where are or were the Solar System's past or present habitable environments?
		Q10.4 Organic synthesis and cycling: Where and how are organic building blocks of life synthesized in the solar system?
		Q10.5 What is the availability of nutrients and other inorganic ingredients to support life?

2023 Decadal Strategic Research
Investigate how photons, charged particles, and micrometeoroids drive escape from different types of surfaces by performing desorption, sputtering, and impact vaporization (i.e., space weathering) laboratory experiments.
Determine the source location and origins of Mars methane by making rapid, accurate measurements of methane fluxes at the surface of Mars on hourly to annual timescales, and by returning an atmospheric sample of sufficient concentration to measure methane isotopic fractions indicative of a biotic or abiotic origin.
Investigate the microphysical parameters that influence the formation of clouds in planetary atmospheres (primarily Venus, Mars, and Titan, but also including Triton, and Pluto) by determining the distribution, nature and abundance of clouds and the composition and particle size of the droplets comprising them and cloud condensation nuclei around which they form.
Investigate the conversion of regolith-implanted H and C ions into more complex molecules like water, molecular hydrogen, and methane via laboratory studies and molecular dynamic simulations.
Constrain the origin of Phobos and Deimos, including whether they arose from past Mars rings, by determining their bulk composition and interior structure with in-situ geochemical and geophysical measurements.
Characterize the current orbital evolution of planetary satellite systems across the solar system (including Earth, Jupiter, Saturn, Uranus, and Neptune), and determine if they are in thermal equilibrium, by measuring how the satellite orbits are currently evolving, how their host planet responds to satellite tides (including phase lag), and by measuring satellite heat flows.
Determine if/how tides have shaped the crustal structure of the Moon, by characterizing the three-dimensional structure of its crust through seismology, electromagnetic sounding, heat flow, and other geophysical methods
Characterize volcanic and magmatic processes on the Moon and assess their relationship to tides, crustal structure, and interior processes with in-situ geochemical and geophysical analyses (including seismology, electromagnetic sounding, and heat flow measurements), and/or returned samples from key volcanic and magmatic sites across the Moon
Determine the size and state of the Moon's solid inner core through seismology measurements, electromagnetic sounding, and other geophysical investigations
Determine how, why, and when tectonic and (cryo)volcanic surface features form on rocky and icy satellites through modeling of fractures, fracture systems, fracture-water interactions, and (cryo)magmatic processes in ice and rock shells.
Test the hypotheses for the origin of planetary asymmetries, including the nearside-farside asymmetry on the Moon and elsewhere, by characterizing their magnetospheric and dust environment, and by geological, geochemical, and geophysical investigations of the dichotomies themselves.
Determine the evolution of the climate of Mars and Venus and the timing of changes by measurement of atmospheric gases, chemistry and isotopes in the atmosphere and rocks, and climate modeling.
Characterize organic molecules present on Mars for determination of type, distribution, and source of organic materials to understand organic synthesis there by in-situ measurements and sample return for investigation in Earth laboratories.
Determine the inventory and bioavailability of CHNOPS, particularly reduced carbon and fixed nitrogen, for candidate current and ancient habitable environments on Mars by measurements of mineralogy, chemistry, and isotopes from high-resolution remote sensing, surface missions and returned samples as well as modeling exchanges.
Quantify the impact of the seasonal cycles in the Martian atmosphere on the formation and long-term evolution of CHNOPS species, using telescopic, spacecraft, and in-situ observations of the behavior of aerosols, trace gas abundances and isotopes, as well as observations and models of meteorological behavior and surface fluxes of gases.

LPS-2^{LM}: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/ exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	*Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?*	Q10.6 What controls the energy available for life?
		Q10.7 What controls the continuity or sustainability of habitability?

Geochemically characterize past and present environments with liquid water to determine whether there is/was energy to sustain metabolic processes of life by in-situ or sample analysis of waters and preserved water-formed mineral and chemical species to determine concentrations of major ions, electron donors and acceptors, mineral products, and other relevant chemical species.
Determine the geophysical parameters that control past and present material fluxes in rocky subsurfaces, such as porosity, permeability, heat flux, volcanic flux, and tectonics by geophysical measurement, drilling/coring, change-detection experiments, seismic experiments, and modelling.
Determine the nature, timing, and processes controlling the existence of past habitable environments on Mars bymeasurements in-situ and in returned samples of stratigraphy, petrology, organic content, isotopes in rock, and geochronology in multiple environments covering multiple time periods.
Identify the effects of large impacts on local and planetary habitability by investigating impact sites on potentially habitable bodies, analyzing chemical and isotopic signatures in rock/ice records before and after impacts, modeling the thermal and compositional effects of impacts on planetary atmospheres and surfaces, and improving knowledge of impact flux with time.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-3^{LM}: Reveal inner Solar System volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.	Q3. Origin of Earth and inner solar system bodies. How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer solar system materials incorporated?	Q3.3 How did the Earth/Moon system form?
		Q3.5 How and when did the terrestrial planets and Moon differentiate?
		Q3.6 What established the primordial inventories of volatile elements and compounds in the inner Solar System?
	Q4. Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?	Q4.3 How did collisions affect the geological, geophysical, and geochemical evolution and properties of planetary bodies?
	Q5. Solid body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?	Q5.3 How have surface/near-surface characteristics and compositions of solid bodies been modified by, and recorded, interior processes?
		Q5.5 How have surface characteristics and compositions of solid bodies been modified by, and recorded, external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution. What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?	Q6.1 How do solid-body atmospheres form and what was their state during and shortly after accretion?
		Q6.4 How do planetary surfaces and interiors influence and interact with their host atmospheres?
	Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?	Q10.2 Where are or were the Solar System's past or present habitable environments?
		Q10.3 Water availability: What controls the amount of available water on a body over time?

2023 Decadal Strategic Research
Determine the origin of the Moon's volatile element abundances by completing additional stable isotopic analyses of volatile elements in lunar samples originating from the lunar interior as well as gamma-ray and neutron spectrometer measurements (e.g., K/Th ratios) by spacecraft.
Determine the contribution of outer solar system materials to the inventory of the inner solar system planets through measurements of the volatiles and refractory components of water-rich asteroids and comets by telescopic observations, in-situ measurements, and/or analysis of returned samples.
Precisely determine the elemental and isotopic compositions of Martian mantle and atmospheric volatiles at present and in the past by analyzing carefully selected atmospheric and solid samples with different ages and provenances returned from Mars.
Determine the origin and abundances of volatiles in inner Solar System bodies by conducting geochemical, petrologic, and spectral measurements of these bodies and their associated samples and by coupling results from planetary accretion models, laboratory experiments on volatile behavior, observations of volatile distribution in the asteroid and comet populations, and geochemical measurements from a wide range of parent bodies.
Determine the origin of polar volatiles by obtaining and analyzing the properties of ices found within the permanently shadowed craters located near the lunar and Mercurian poles.
Determine the range of volatile contents and species in planetary melts in igneous samples from Mars, the Moon and asteroids, to constrain the range and variety in planetary volatile contents, and factors influencing melt generation, composition, and eruptibility using Earth-based laboratory measurements of returned samples and/or meteorites.
Determine the origin, time of delivery, vertical and lateral distribution and current cycling of cold-trapped lunar volatiles via in-situ analyses of isotopes (e.g., Deuterium/Hydrogen), sulfur, organics, abundance and distribution of volatiles, and local exospheric measurements.
Derive the sources of exospheric volatiles by measuring the distribution, composition, and abundance of surface volatiles (including the permanently shadowed regions) on solid bodies including the Moon, Mercury, Ceres, and outer planet satellites such as Europa.
Investigate how and where stable water ice deposits form on Mars by measuring their distribution through radar and spectroscopic mapping from orbit, and by measuring the ice vertical distribution, volatile fluxes, and environmental drivers at the surface.
Determine the distribution of past and present subsurface oceans – fully liquid and muddy – and their historical evolution through detailed investigations using detailed geological/geophysical investigations and modeling efforts coupled with a search for oceans by remote sensing.
Establish whether liquid water is present on Mars today in the subsurface by geochemical measurements of ices and recent hydrous minerals and geophysical measurements to probe the upper crust.
Determine the distribution, history, and processes driving the availability of ice and liquid water on Mars over time, combining mapping stratigraphy and mineralogy, measurements of chemical, mineralogic, and isotopic measurements in-situ and from returned samples, sounding of the subsurface, models for geomorphic features and climate processes, and constraints on chronology from in-situ radiometric dating and measurements on returned samples.
Determine the amount and origin of water ice on the Moon and Mercury by sampling ice, determining its spatial distribution, measuring H and O isotopes, and determining the nature and abundance of contaminants within the ice as a means of understanding sources of water in the inner solar system.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-4^M^: Advance understanding of the origin of life in the Solar System by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the Solar System beyond Earth.	Q4. Impacts and dynamics. How has the population of solar system bodies changed through time, and how has bombardment varied across the solar system? How have collisions affected the evolution of planetary bodies?	Q4.3 How did collisions affect the geological, geophysical, and geochemical evolution and properties of planetary bodies?
	Q9. Insights from Terrestrial Life. What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface, and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?	Q9.1 What were the conditions and processes conducive to the origin and early evolution of life on Earth, and what do they teach us about the possible emergence and evolution of life on other worlds?
	Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?	Q10.1 What is Habitability?
		Q10.2 Where are or were the Solar System's past or present habitable environments?
		Q10.3 Water availability: What controls the amount of available water on a body over time?
		Q10.4 Organic synthesis and cycling: Where and how are organic building blocks of life synthesized in the solar system?
		Q10.5. What is the availability of nutrients and other inorganic ingredients to support life?

2023 Decadal Strategic Research
Determine the nature and global distribution of hydrothermal deposits in large Martian or Cerean craters that may have been habitable zones by mapping at high resolution the mineralogy, composition and distribution of these deposits or returning samples.
Characterize the surface and subsurface processes (e.g., impactor flux, atmospheric conditions, volcanism, tectonism) and the range of chemical inventories (e.g., volatiles, organics) present during the emergence of Earth's nascent biosphere through modeling, analyses and measurements of solar system materials (asteroids, comets, interplanetary dust particles, and meteorites), investigation of Earth's isotopic record, and estimation of fluxes recorded and volatiles deposited on ancient, well preserved inner solar system planetary surfaces (Moon and Mercury).
Characterize how the early, dynamic solar system environment shaped Earth's environments and the subsequent emergence and evolution of life therein by determining a reliable absolute chronologic record of the early bombardment of the Earth-Moon system, especially prior to 3.7 Ga.
Characterize conditions on known and candidate modern habitable environments in the solar system, e.g., on Mars, Enceladus, Europa and other bodies, by measuring water chemistry, mineralogy, ice composition, gases, and organic molecules to assess whether conditions exist that could support life
Determine the character, timing, and duration of past habitable environments on Mars using chemical, mineralogical, textural, isotopic, and organic measurements from orbit, in-situ and on returned samples
Determine the extent of present and former habitable environments across the solar system by making measurements that determine the past and present existence of liquid water, the organic content, and the availability of nutrients and metabolic energy sources on terrestrial planets and ocean worlds.
Determine the distribution of past and present subsurface oceans –fully liquid and muddy– and their historical evolution through detailed investigations using detailed geological/geophysical investigations and modeling efforts coupled with a search for oceans by remote sensing.
Determine the evolution of the climate of Mars and Venus and the timing of changes by measurement of atmospheric gases, chemistry and isotopes in the atmosphere and rocks, and climate modeling.
Establish whether liquid water is present on Mars today in the subsurface by geochemical measurements of ices and recent hydrous minerals and geophysical measurements to probe the upper crust.
Determine the distribution, history, and processes driving the availability of ice and liquid water on Mars over time, combining mapping stratigraphy and mineralogy, measurements of chemical, mineralogic, and isotopic measurements in-situ and from returned samples, sounding of the subsurface, models for geomorphic features and climate processes, and constraints on chronology from in-situ radiometric dating and measurements on returned samples.
Determine the amount and origin of water ice on the Moon and Mercury by sampling ice, determining its spatial distribution, measuring H and O isotopes, and determining the nature and abundance of contaminants within the ice as a means of understanding sources of water in the inner solar system.
Characterize organic molecules present on Mars for determination of type, distribution, and source of organic materials to understand organic synthesis there by in-situ measurements and sample return for investigation in Earth laboratories.
Determine the inventory and bioavailability of CHNOPS, particularly reduced carbon and fixed nitrogen, for candidate current and ancient habitable environments on Mars by measurements of mineralogy, chemistry, and isotopes from high-resolution remote sensing, surface missions and returned samples as well as modeling exchanges.
Quantify the impact of the seasonal cycles in the Martian atmosphere on the formation and long-term evolution of CHNOPS species, using telescopic, spacecraft, and in-situ observations of the behavior of aerosols, trace gas abundances and isotopes, as well as observations and models of meteorological behavior and surface fluxes of gases.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-4^M: Advance understanding of the origin of life in the Solar System by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the Solar System beyond Earth.	*Q10. Dynamic habitability. Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?*	Q10.6 What controls the energy available for life?
		Q10.7 What controls the continuity or sustainability of habitability?
	Q11. Search for life elsewhere. Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?	Q11.1 Path to biogenesis: What is the extent and history of organic chemical evolution, potentially leading towards life, in habitable environments throughout the Solar System? How does this inform the likelihood of false positive life detections?
		Q11.2 Biosignature potential: What is the biosignature potential (i.e., the reliability, detectability, and survivability of biosignatures) in habitable environments beyond Earth? What are the possible sources of false positives and false negatives?

2023 Decadal Strategic Research
Geochemically characterize past and present environments with liquid water to determine whether there is/was energy to sustain metabolic processes of life by in-situ or sample analysis of waters and preserved water-formed mineral and chemical species to determine concentrations of major ions, electron donors and acceptors, mineral products, and other relevant chemical species.
Characterize the compositional and geological heterogeneity of potentially habitable worlds at progressively smaller scales (km- to cm-scale) to identify locales where chemical energy is or was more available by identification of mineralized fractures, reaction fronts, permeability boundaries, sites of ocean-ice exchange, and other interfaces via orbital remote sensing and in-situ landscape- and microscopic-scale characterization.
Determine the geophysical parameters that control past and present material fluxes in rocky subsurfaces, such as porosity, permeability, heat flux, volcanic flux, and tectonics by geophysicalmeasurement, drilling/coring, change-detection experiments, seismic experiments, and modelling.
Determine the kinetics of chemical reactions relevant to energy supply and material availability for life under conditions (past or present) on planetary bodies in the solar system by conducting laboratory experiments.
Determine the nature, timing, and processes controlling the existence of past habitable environments on Mars bymeasurements in-situ and in returned samples of stratigraphy, petrology, organic content, isotopes in rock, and geochronology in multiple environments covering multiple time periods.
Identify the effects of large impacts on local and planetary habitability by investigating impact sites on potentially habitable bodies, analyzing chemical and isotopic signatures in rock/ice records before and after impacts, modeling the thermal and compositional effects of impacts on planetary atmospheres and surfaces, and improving knowledge of impact flux with time.
Understand the diversity and controls on rates and styles of recycling of surface materials by remote sensing of evidence of these processes on relevant worlds, and by developing models for lithosphere dynamics and (cryo)volcanism that account for the thermal and orbital evolution of bodies, and the rheological and compositional evolution of their interiors.
Determine the organic molecule inventory, including extent of molecular complexity and degree of organization, of currently or previously habitable environments throughout the solar system (e.g., Enceladus, Europa, Titan, Ceres, Mars—see Question 10 for full list) with spacecraft in-situ and/or remote sensing observations, telescopic observations or sample return.
Identify relevant chemical pathways that can lead from prebiotic chemistry to biochemistry in currently or previously habitable environments throughout the solar system as a function of geochemical state by characterizing each environments' geochemistry, physicochemical conditions and associated prebiotic (or potentially biotic) reactants, intermediates and products using spacecraft in-situ and/or remote sensing observations, telescopic observations, and via laboratory/experimental and modeling/theoretical research.
Characterize the extent of molecular complexity and degree of organization achievable for an organic molecule inventory in the absence of life in currently or previously habitable environments throughout the solar system using laboratory/experimental and modeling/theoretical research as well as field work and astromaterial analysis to explore the parameter space (e.g., temperature, pressure, pH, reactants, and catalysts/substrates).
Ascertain how levels of organic inventory, molecular complexity and/or degree of organization that can be achieved in the absence of life might inform the search for life elsewhere using laboratory/experimental and modeling/theoretical research as well as field work and astromaterial analysis.
Evaluate possible sources of false positives for organic chemical biosignatures with spacecraft in-situ and/or remote sensing observations, telescopic observations and sample return from worlds unlikely to host life (e.g., the Moon, comets, asteroids) and uninhabited regions of previously or currently habitable environments (e.g., the surface of Mars) in an effort to assess the production and/or delivery rate of abiotic organic molecules that might mimic biological organic molecules and establish a baseline against which measurements in habitable environments can be compared. This also includes analysis of astromaterials, as well as theoretical and laboratory approaches.
Determine which attributes of terrestrial life can serve as definitive biosignatures in the search for life beyond Earth by theoretical, field, and laboratory research activities that inform on the range of morphological and chemical (organic, isotopic, mineralogical, atmospheric) signatures produced by living systems, with a complementary emphasis on what contextual evidence is required to confidently recognize a potential biosignature.

Moon to Mars Objective	2023 Planetary Science and Astrobiology Decadal Questions	2023 Decadal Strategic Questions
LPS-4^{M}: Advance understanding of the origin of life in the Solar System by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the Solar System beyond Earth.	*Q11. Search for life elsewhere. Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?*	*Q11.2 Biosignature potential: What is the biosignature potential (i.e., the reliability, detectability, and survivability of biosignatures) in habitable environments beyond Earth? What are the possible sources of false positives and false negatives?*
		Q11.3 Life detection: Is or was there life elsewhere in the Solar System?
		Q11.4 Life characterization: What is the nature of life elsewhere, if it exists?

2023 Decadal Strategic Research
Constrain the biomass and/or bioenergetic potential of habitable environments throughout the solar system through measurements of environmental factors (e.g., pH, temperature, salinity, redox potential) and fluxes (e.g., energy, nutrients) with spacecraft in-situ and/or remote sensing observations, or returned sample analysis; and theoretical, field, and laboratory research activities to understand how modern and ancient environmental properties and processes on Earth relate to biomass production to inform the development of life detection strategies and technology (see also Question 9).
Characterize the range of processes that affect the production and preservation of detectable biosignatures in habitable environments by theoretical, field, and laboratory research activities that inform us about the pathways and rates of biosignature production, preservation, and destruction, be they morphological or chemical (organic, isotopic, mineralogical, atmospheric) in nature. Tie those studies to in-situ, remote, and/or telescopic measurements of specific environmental properties of habitable worlds in the solar system (e.g., Enceladus, Europa, Titan, Ceres, Mars—see Question 10 for full list) that might act to enhance, preserve, or destroy biosignatures.
Establish a comprehensive, standardized framework for evaluation of biosignatures, including the potential for biosignatures, false positives, and false negatives, through community-level dialog and consensus, supported by laboratory/experimental and modeling/theoretical research as well as field work.
Develop and validate effective life detection payloads that support the search for evidence of life beyond Earth by maturing end-to-end technologies for sample acquisition, sample handling/ preparation and sample analysis, and by prioritizing the early integration and validation of these technologies and instrument suites.
Search for evidence of present life in environments beyond Earth that currently have a high biological potential by looking for multiple, independent biosignatures with spacecraft in-situ observations or in samples returned to Earth, informed by laboratory/experimental and modeling/theoretical research as well as field work of currently habitable environments on Earth.
Search for evidence of past life in environments beyond Earth that had a high biological potential in the past by looking for multiple, independent biosignatures with spacecraft in-situ observations or in samples returned to Earth, informed by laboratory/experimental and modeling/theoretical research as well as field work of ancient life on Earth.
Search for evidence of life 'not as we know it' in environments beyond Earth by looking for multiple, independent biosignatures with spacecraft in-situ observations or in samples returned to Earth, informed by laboratory/experimental and modeling/theoretical research of putative organisms that might utilize unique biochemistry or alternative essential elements or solvents.
Determine the optimal sampling strategy to minimize the likelihood of a false negative life detection measurement (or set of measurements) due to heterogeneous distributions of biological signals or other factors by employing laboratory studies and modeling/theoretical research in conjunction with field studies of biological oases and environments with severe nutrient/energy limitations on Earth.
Develop and implement analysis techniques to evaluate the likelihood of forward contamination in life-detection missions through models of contamination transfer from spacecraft surfaces and by improving hardware protection/cleaning methods, in order to meet the stringent contamination requirements imposed by life-detection science.
Investigate the chemical environments of Europa and Enceladus that are relevant to potential biochemistry through measurements of possible metabolic reactants and products (organic and inorganic compounds), reaction conditions (e.g., temperature, pressure, Eh, pH), rates and catalysis (e.g., mineral surfaces, trace elements), as well as the structure of biomolecules at the surface and in waters sourced from the subsurface.
Determine whether any life present in Martian materials might share ancestry with Earth through measurement of any biomolecules as part of the organic chemical inventory to assess their function (including, for ancient life, their pre-degradation form) and what they reveal about the co-evolution of Mars's life and climate.
Prepare for characterizing life in the subsurface of ocean worlds by determining the heterogeneity of thicknesses of ice shells via planetary mission data as well as validating and deploying emerging technologies for life characterization, and maturing technology for accessing the subsurface for exploration, by work in the field and in the laboratory.
Develop viable solutions to technical challenges for curation of samples to be returned from Mars and ocean worlds that will preserve their scientific integrity, including biosafe curation coupled (for ocean worlds) with cold conditions.
Characterize any form of life discovered beyond Earth, and investigate its relatedness, or lack thereof to life on Earth through measurements of its biochemical, morphological, and/or physiological/metabolic traits with spacecraft in-situ observations or in samples returned to Earth.

Moon to Mars Objective	Active Solar and Space Decadal Objectives	Active Solar and Physics Decadal Science Challenges
HS-1[LM]: Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.	Key Science Goal 1. Determine the origins of the Sun's activity and predict the variations in the space environment.	SHP-3 Determine how magnetic energy is stored and explosively released and how the resultant disturbances propagate through the heliosphere.
		SWMI-3 Determine how coupling and feedback between the magnetosphere, ionosphere, and thermosphere govern the dynamics of the coupled system in its response to the variable solar wind
		AIMI-1 Understand how the ionosphere-thermosphere system responds to, and regulates, magnetospheric forcing over global, regional, and local scales.
		AIMI-2 Understand the plasma-neutral coupling processes that give rise to local, regional, and global-scale structures and dynamics in the AIM system.
		AIMI-3 Understand how forcing from the lower atmosphere via tidal, planetary, and gravity waves influences the ionosphere and thermosphere.
HS-2[LM]: Determine the history of the Sun and Solar System as recorded in the lunar and Martian regolith.	Key Science Goal 4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.	SHP-4 Discover how the Sun interacts with the local interstellar medium.
		SWMI-4 Critically advance the physical understanding of magnetospheres and their coupling to ionospheres and thermospheres by comparing models against observations from different magnetospheric systems.
		AIMI-4 Determine and identify the causes for long-term (multi-decadal) changes in the AIM system
HS-3[LM]: Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Martian, and near-surface environments as laboratories.	Key Science Goal 4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.	SHP-2 Determine how the Sun's magnetism creates its hot, dynamic atmosphere.
		SHP-3 Determine how magnetic energy is stored and explosively released and how the resultant disturbances propagate through the heliosphere.

Other Relevant Documents
• 2007 Heliophysics Science and the Moon (Section 2.0) • 2019 National Space Weather Strategy and Action Plan • 2020 NASA Space Weather Strategy • 2020 Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act • 2021 NASA Space Weather Science and Observation Gap Analysis • 2021 National Academy: Planning the Future Space Weather Operations and Research Infrastructure • 2022 National Academy: Space Weather Workshop Phase II - TBA
• 2007 Heliophysics Science and the Moon (Section 3.0)
• 2007 Heliophysics Science and the Moon (Section 1.0, 4.0) • 2021 Plasma Science: Enabling Technology, Sustainability, Security, and Exploration • 2007 Heliophysics Science and the Moon (Section 1.0, 4.0) • 2021 Plasma Science: Enabling Technology, Sustainability, Security, and Exploration

Moon to Mars Objective	Active Solar and Space Decadal Objectives	Active Solar and Physics Decadal Science Challenges
HS-3[LM]: Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Martian, and near-surface environments as laboratories.	*Key Science Goal 4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.*	SHP-4 Discover how the Sun interacts with the local interstellar medium.
		SWMI-1 Establish how magnetic reconnection is triggered and how it evolves to drive mass, momentum, and energy transport.
		SWMI-2 Identify the mechanisms that control the production, loss, and energization of energetic particles in the magnetosphere.
		SWMI-3 Determine how coupling and feedback between the magnetosphere, ionosphere, and thermosphere govern the dynamics of the coupled system in its response to the variable solar wind.
		SWMI-4 Critically advance the physical understanding of magnetospheres and their coupling to ionospheres and thermospheres by comparing models against observations from different magnetospheric systems.
		AIMI-1 Understand how the ionosphere-thermosphere system responds to, and regulates, magnetospheric forcing over global, regional, and local scales.
		AIMI-2 Understand the plasma-neutral coupling processes that give rise to local, regional, and global-scale structures and dynamics in the AIM system.
HS-4[LM]: Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.	Key Science Goal 2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.	SHP-3 Determine how magnetic energy is stored and explosively released and how the resultant disturbances propagate through the heliosphere.
		SHP-4 Discover how the Sun interacts with the local interstellar medium.

Other Relevant Documents

- *2007 Heliophysics Science and the Moon (Section 1.0, 4.0)*
- *2021 Plasma Science: Enabling Technology, Sustainability, Security, and Exploration*
- *2007 Heliophysics Science and the Moon (Section 1.0, 4.0)*
- *2021 Plasma Science: Enabling Technology, Sustainability, Security, and Exploration*

- 2007 Heliophysics Science and the Moon (Section 1.0)

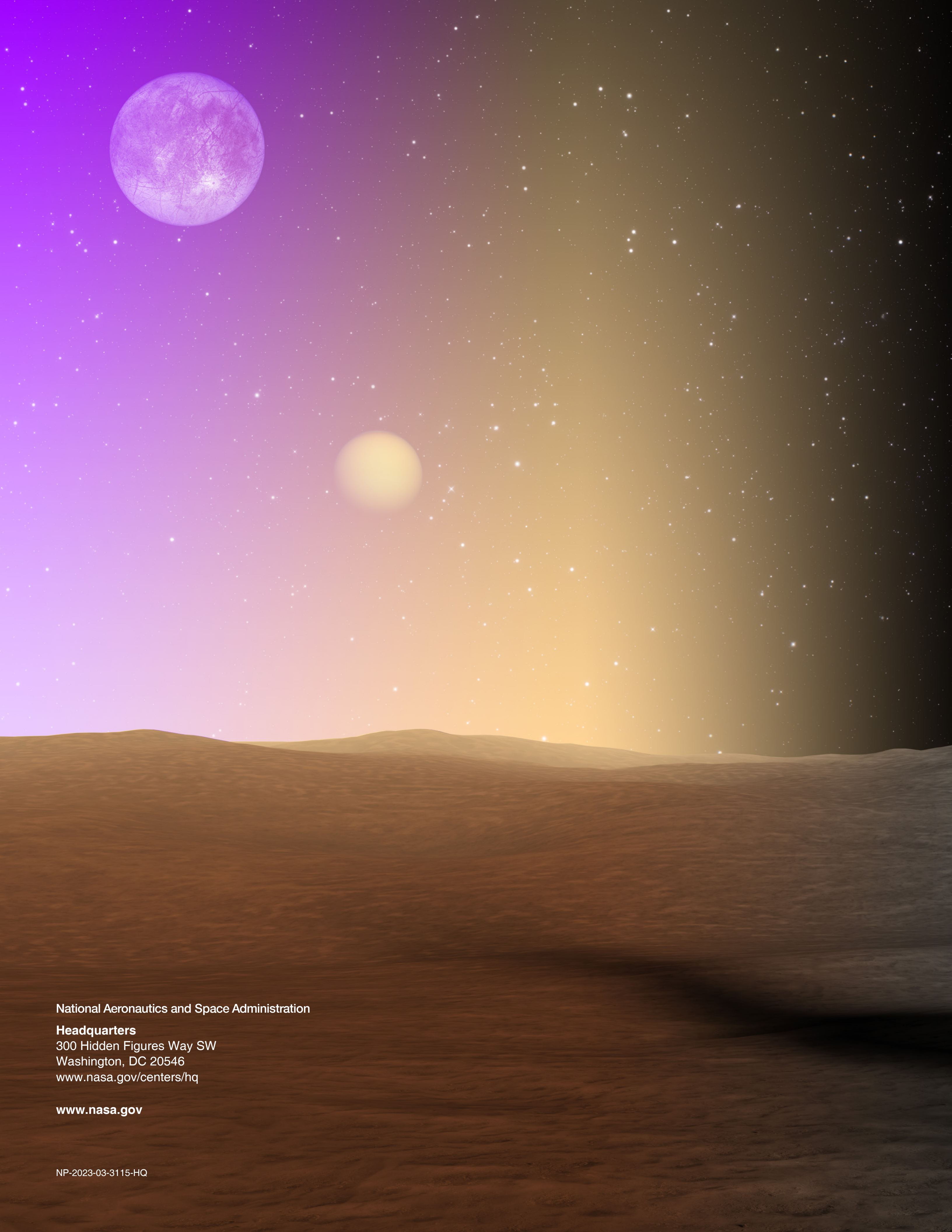
Moon to Mars Objective	Active BioSciences Decadal Objectives (to be updated with upcoming decadal)	
HBS-1^{LM}: Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants	**Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era** (2011 BPS Decadal Survey; to be updated with upcoming 2023 Decadal release) Due to the fundamental science nature of the 2010 Decadal report, most of the recommendations are applicable to and support the Decadal Report finding above.	Achieving the goals of the Exploration Initiative will require a greater understanding of life and physical sciences phenomena in microgravity as well as in the partial gravity environments of the Moon and Mars (from 2011 BPS Decadal Report)
	Research for the Future in Space: The Role of Life and Physical Sciences (2012; Supplement to the 2011 BPS Decadal Report) Investigation Priority Sections to address critical knowledge gaps and understanding:	1) Issues with Bone Loss
		2) Nutrition and Space Foods
		3) Shifts in Astronaut Health during Long Periods in Space
		4) The Roles of Plants and Microbial Growth
		5) The Risk of Cellular and Genetic Changes in Long-Term Space Travel
	Thriving in Deep Space (TIDES) Research Question 1: Understand how animals and model organisms respond to the space environment to enable humans to thrive in space Research Question 2: Understand how plants grow in space to enable human space missions by providing nutrition and enhancing behavioral health	1) Systems Biology
		2) Genetic Engineering Plants
		3) Plant Responses to Lunar Regolith and Simulants
		4) 3D Tissue and Organ-on-Chip Models

Moon to Mars Objective	Human Research Program Roadmap Integrated Research Plan
HBS-2LM: Evaluate and validate progressively Earth-independent crew health & performance systems and operations with mission durations representative of Mars-class missions.	Evaluate and validate progressively Earth-independent crew health & performance systems and operations.
	Test crew health & performance with the hazard environments, mission durations, and systems representative of Mars-class missions.
HBS-3LM: Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.	Evaluate changes to the human system and validate countermeasures to mitigate impacts to overall crew health & performance with human subject research.
	Evaluate the interaction of exploration habitation systems and spaceflight hazards and validate crew health & performance.
	Evaluate and validate operational implementation of critical tasks and human factors for adequate crew health & performance.

https://humanresearchroadmap.nasa.gov/

Moon to Mars Objective	Active Physical Sciences Decadal Objectives	Active Physical Sciences Decadal Science
PPS-1^{L}: Conduct astrophysics and fundamental physics investigations of deep space and deep time from the radio quiet environment of the lunar far side.	Discovery Area: The Dark Ages as a Cosmological Probe	21 cm and molecular line intensity mapping of the Dark Ages and reionization era as both the discovery area for the next decade and as the likely future technique for measuring the initial conditions of the universe in the decades to follow
PPS-2^{LM}: Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.	**Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era (released 2011 BPS Decadal Survey; to be updated with upcoming 2023 Decadal release)** Due to the fundamental science nature of the 2011 Decadal report, most of the recommendations are applicable to and support the Decadal Report finding above.	Achieving the goals of the Exploration Initiative will require a greater understanding of life and physical sciences phenomena in microgravity as well as in the partial gravity environments of the Moon and Mars. (from 2011 BPS Decadal Report)
	Research for the Future in Space: The Role of Life and Physical Sciences (2012; Supplement to the 2011 BPS Decadal Report) Investigation Priority Sections to address critical knowledge gaps and understanding:	1) The Nature of Fluids
		2) Physics in Space
		3) Issues in Fire Behavior and Safety
		4) The Matter of Materials
		5) Exploring Space and Time
		6) Living Off the Land

Active Physical Sciences Decadal Strategic Investigations
The FARSIDE array is listed as a candidate Probe-class mission also in the Decadal Survey. Science: z > 10 neutral hydrogen and SETI search on lunar far side; exoplanets; heliophysics
21 cm interferometers: (C-2a) Dark sector small-scale structure; (C-3b) support modeling of CMB optical depth; (CDA1) unusual IGM temperature histories; (CDA2) primordial density mapping; Long-term, map at z > 50; decadalscale, map at reionization epoch and lower redshifts
Recycling Air and Water in Spacecraft
Understanding altered granular physics and fluid-like behaviors
Fluid Physics - small forces
Cryogenic rocket fuels
Planetary water retrieval and processing
Granular physics and physical properties
Combustion and Fire Behavior
Prevention, Detection, Suppression
Material's microstructure and quality
Relationship between a material's properties and structure
Cold Atoms, atomic clocks
Complex fluid and soft matter
Harnessing Non-Terrestrial Resources for Exploration Technologies
Space Construction with Earth-Tested Methods



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NP-2023-03-3115-HQ