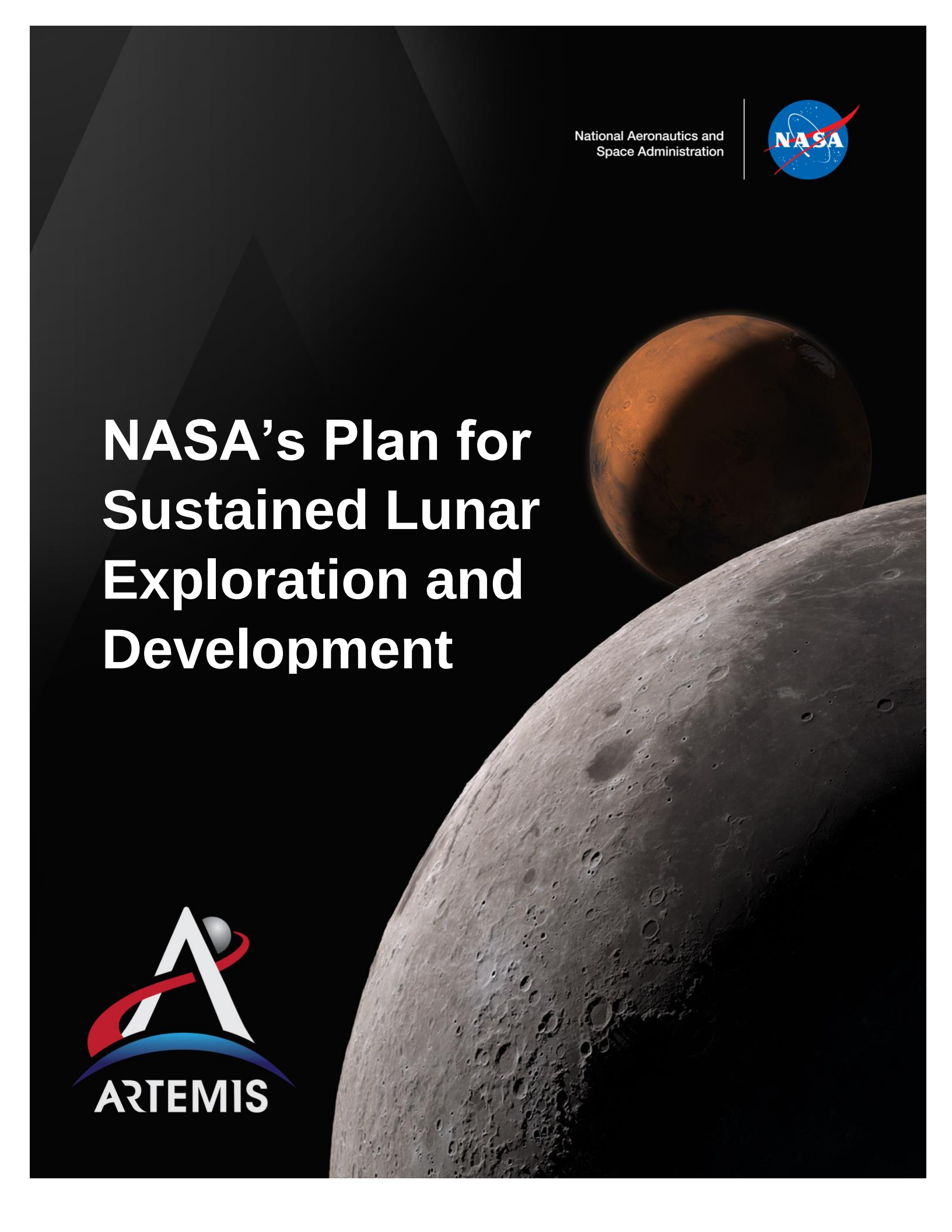
National Aeronautics and Space Administration



NASA's Plan for Sustained Lunar Exploration and Development

ARTEMIS

NASA'S PLAN FOR A VIBRANT LUNAR FUTURE

"Lead 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."

– President Trump, Space Policy Directive 1, December 11, 2017

"The NASA Administrator shall submit a plan to the Chairman of the National Space Council for sustainable lunar surface exploration and development, including necessary technologies and capabilities to enable initial human exploration of Mars."

– Vice President Pence, 6th Public Meeting of the National Space Council, August 20, 2019

OVERVIEW

The Moon is the gateway to the solar system. A world equivalent to an entire continent that human feet have touched only a few times. As Earth's nearest planetary neighbor, the Moon has profound potential to be a source of new scientific advances and economic growth. It is also the best place for us to test our deep space systems and operations in preparation for the first human mission to another planet: Mars. Over the next decade, the Artemis program will lay the foundation for a sustained long-term presence on the lunar surface and use the Moon to validate deep space systems and operations before embarking on the much farther voyage to Mars.

Over the coming decades and generations, our presence will grow to use and develop the extensive resources of the Moon, including its water and metal deposits. As the Moon unveils her secrets, scientific interest continues to grow. In addition to enabling scientific understanding of the formation of the Earth and the solar system through lunar geology and chemistry, exploration of the Moon will enable ground-breaking scientific discoveries about the universe, including through radio astronomy from the incredible vantage point of the far side of the Moon. As in the skies and now low-Earth orbit, NASA's scientific and exploration efforts lead the way and economic development follows. The Artemis program will similarly enable commercial opportunities on the lunar surface, beginning with the first U.S commercial lunar deliveries next year.

The Moon is more than a physical destination. A core focus of Artemis is to extend the nation's geo-strategic and economic sphere to encompass the Moon with international partners and private industry. The United States will build confidence among its commercial, U.S. government, and international partners by leading the development of clear policy principles to support civil space exploration with an initial emphasis on the Artemis program. Specifically, the

U.S. will establish a predictable and safe process for the extraction and use of space resources under the auspices of the Outer Space Treaty.

This document covers and responds to the Chairman of the National Space Council's direction to provide a plan for a sustained lunar presence, including the technologies and capabilities to enable the first human mission to Mars. For millennia humanity has looked at the Moon in wonder and awe. As the United States leads the development of a sustained presence on the Moon together with commercial partners and international partners, our presence on the Moon will serve as a constant reminder of the limitless potential of humanity. It will continue to inspire humanity as we seek ever more distant worlds to explore - starting with Mars.

The first human mission to Mars will mark a transformative moment for human civilization. Establishing a sustained lunar presence and taking the initial steps toward the first human mission to Mars will be the greatest feat of engineering, and the greatest voyage of exploration and discovery, in human history. These missions will drive technology and innovation using the country's unparalleled scientific capabilities, dynamic economy, and robust industrial base. These missions will inspire generations of science, technology, engineering, and mathematics (STEM) professionals and countless other disciplines, while offering opportunities to domestic partners in government, industry, and academia.

Most importantly, the accomplishments of the Moon to Mars approach will assure that America remains at the forefront of exploration and discovery. The United States is still the only nation to have successfully landed humans on the Moon and spacecraft on the surface of Mars. As other nations steadily increase their presence and spending, American leadership is now called for to lead the next phase of humanity's quest to create a future comprised of endless discovery and growth in the final frontier.

THE ARTEMIS GENERATION

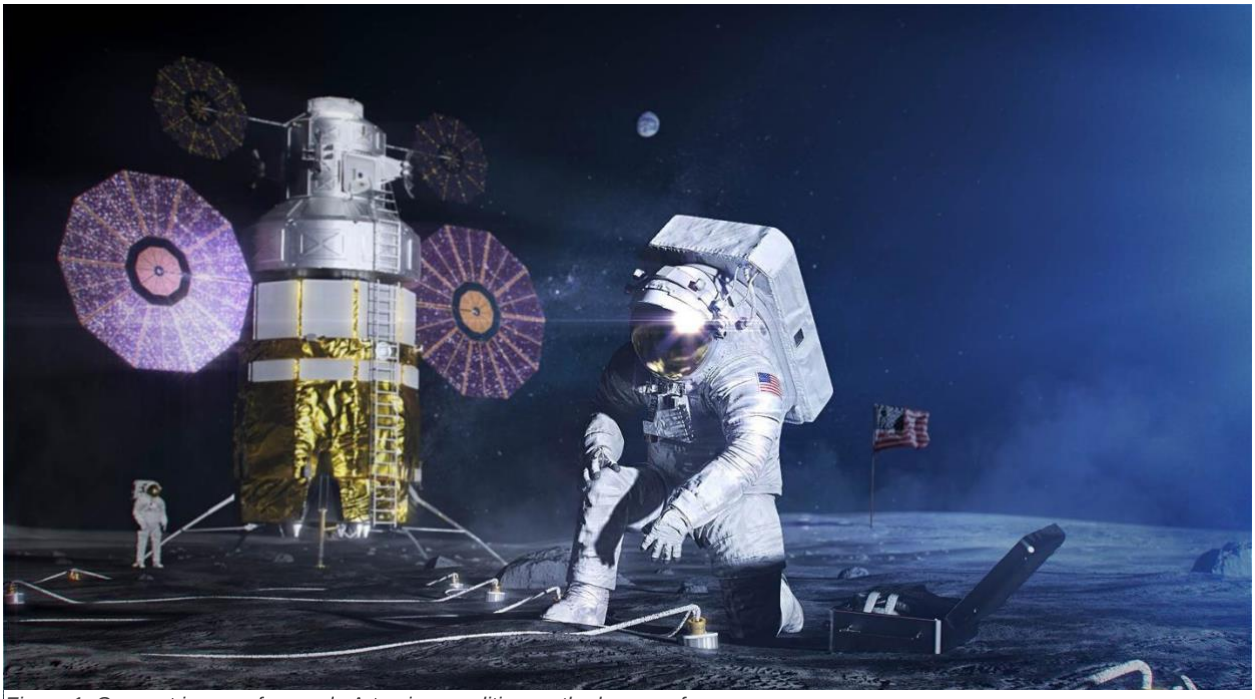


Figure 1: Concept image of an early Artemis expedition on the lunar surface.

Everyone born after the year 2000 has always known a world where people have been living in space. In this decade, we will all see humans walking on the Moon again – this is the Artemis Generation. Artemis, the twin sister of Apollo, will put in place the key infrastructure on and around the Moon that will be built upon and leveraged for generations to come.

Americans will return to the Moon in 2024. Following this 2024 landing, we will develop a sustained, strategic presence at the lunar South Pole called the Artemis Base Camp. Our activities at our Artemis Base Camp over the next decade will pave the way for long-term economic and scientific activity at the Moon, as well as for the first human mission to Mars in the 2030s.

Starting next year, a steady stream of robotic precursors and technology demonstrations will begin lunar operations. The Moon is a fundamental part of our planet's past and future. Although Americans first walked on its surface more than 50 years ago, our explorers left only fleeting footprints at a few sites, spending a total of 16 days on the lunar surface. These missions were all in the equatorial region, with a total traverse of less than 100kms (~62 miles) – on a body whose surface area is the size of Africa.

This next wave of lunar exploration will be fundamentally different. It starts with American expeditions to the vicinity of the Moon in 2023, and landing astronauts on the surface in 2024. This will be the first chance for most people alive today to witness a human lunar encounter and landing – a moment when, in awe and wonder, the world holds its breath. America will not stop there – this will be the opening chapter of a new era of discovery and exploration.

NASA'S THREE DOMAIN EXPLORATION STRATEGY

Artemis is the core of NASA's exploration and human spaceflight plans for the next decade. Artemis builds upon ongoing human spaceflight efforts conducted aboard the International Space Station (ISS) and prepares the way for future human spaceflight programs, including the first human mission to Mars. NASA's overall Level Zero Goals for exploration encompass these three primary domains – low-Earth orbit, the Moon, and Mars.

Figure 2: The transition to low-Earth orbit has already begun. Two commercial cargo vehicles, SpaceX's Dragon and Northrop Grumman's Cygnus, service the International Space Station.

NASA Exploration Level Zero Goals

- Transition U.S. human spaceflight in low-Earth orbit to commercial operations, which support NASA and its partners. Use the ISS and new commercial facilities as testbeds for exploration technologies and to nurture emerging commercial applications.
- Advance long-term robotic exploration of the Moon with robust commercial and international partnerships.
- Land American astronauts on the Moon and return them safely.
- Expand U.S. human spaceflight operations at the Moon to support sustained lunar surface activities and to demonstrate elements of a Mars-forward architecture.
- Continue U.S. leadership at Mars by advancing robotic access in preparation for human exploration.
- Engage and inspire America and the world along each step of the way.

Pursuing these goals will ensure our current and future activities in low-Earth orbit can enable Artemis, and that Artemis enables the future exploration of Mars.

NASA has developed a strategy for achieving the Level Zero Goals that includes: a combination of robotic and human missions; architectures that build off of key, enabling hardware elements already in development; new technologies that will expand future options and operations; and new developments which will engage the NASA workforce, industry, and international partners to encourage innovative capabilities and harness competitive and cooperative energies. These efforts are being integrated into a sequence of missions that start with a near-term return of humans to the Moon, and then continue with a set of missions on and around the Moon that will lay the foundation for a sustainable presence. Ultimately, the experiences gained, and technologies demonstrated by these lunar operations will support a historic first human mission to Mars. Conducting scientific exploration synergistically with crew and robotic explorers teaches us effective techniques that can be applied as we push the boundaries of space exploration.

ROBOTIC MISSIONS

Our return to the Moon begins with robots. For more than a decade, NASA's Lunar Reconnaissance Orbiter has been imaging and mapping the Moon for scientific research and in preparation for a human return. NASA's new Commercial Lunar Payload Services (CLPS) initiative has already selected the first two robotic missions that, beginning in 2021, will deliver science and commercial payloads to the surface of the Moon. NASA has also committed to using this approach to deliver its next robotic lunar rover, the Volatiles Investigating Polar Exploration Rover (VIPER), which will conduct science investigations of the lunar volatiles at the Moon's South Pole. The data produced by VIPER will inform future in-situ resource utilization (ISRU) technologies. On the lunar surface we will demonstrate precision landing, starting with CLPS deliveries to build experience and improve capabilities that will enhance all future landings, human and robotic. Later, the CLPS approach will be used to deliver other large cargo elements in direct support of human lunar missions.

Overall, while orbital missions have provided extensive information about the lunar surface and its potential resources, robotic lunar surface scouts are essential to validate these observations and prepare for human habitation and utilization of the Moon's rich array of resources from volatiles to minerals. Landers and rovers provide excellent platforms to demonstrate technologies that will enable greater lunar surface mission capabilities and have applications that extend beyond the Moon to Mars initiative, such as terrestrial robotic mining systems and next-generation power storage. Multiple landers will provide a global view of the Moon and its resources. Rovers will be used to explore the surface more extensively, carrying a variety of instruments including ISRU experiments that will generate detailed information on the availability and extraction of usable resources (e.g., oxygen and water).

These robotic efforts will unleash a broad array of inquiry and scientific investigations. The Moon is a natural laboratory to study planetary processes and evolution, and a platform from which to observe the universe. Bombarded by solar and cosmic radiation for billions of years

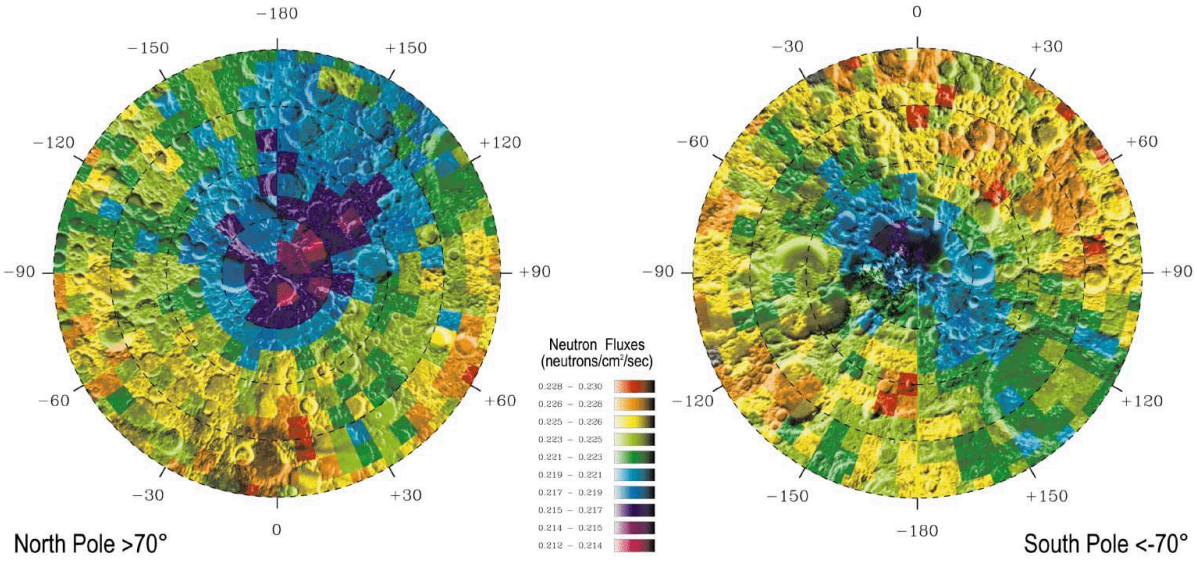


*Figure 3: **Image Above:** The dark blue and purple areas at the Moon's poles indicate neutron emissions that are consistent with hydrogen-rich deposits covered by desiccated regolith. These hydrogen signatures are possible indications of water in the form of water or hydrated minerals. Feldman et al., Science, 281, 1496, 1998.*

and left largely undisturbed, the Moon is a historic archive of our Sun and solar system. Scientific discoveries are locked in its regolith that could lead to improved understanding of our own planet and its evolution. The far side of the Moon offers an unparalled window to look back into the beginning of the universe. It also harbors resources, such as water, that are among the rarest and most precious commodities in space, offering potential sustenance and fuel for future explorers.

THE EARLY ARTEMIS MISSIONS

The foundation for our return to the Moon is NASA's Orion spacecraft and Space Launch System (SLS). The Orion spacecraft has been designed for deep space operations around the Moon for up to four crew members, and the SLS is the powerful heavy-lift rocket designed to launch it, and potentially other high-mass cargo to the lunar environment. Added to these are the two newest elements of the lunar return architecture under contract, the power and propulsion element (PPE) and the habitation and logistics outpost (HALO). Together they form the Gateway's foundation as the Artemis lunar orbiting platform. Early Gateway operations will be autonomous, with help from NASA's Mission Control Center at Johnson Space Center in Houston to conduct systems checkouts and capture critical scientific data about the deep space environment. Orion will deliver the first crew to Gateway when the human landing system (HLS) capability can enable lunar expeditions to be staged from the stable Gateway orbit. Building confidence in this system of an orbiting command module and deployable landers will serve as a critical analog for human missions to the surface of Mars. It will also serve as a strategic capability – allowing access and presence in the orbital lanes around the Moon and to the rest of the solar system.

Figure 4: Concept image of the Space Launch System launching from Kennedy Space Center

The Artemis program begins with an uncrewed flight test of the SLS and Orion (Artemis I), then a crewed flight test (Artemis II). Artemis I will see SLS send an uncrewed Orion 280,000 miles from Earth, thousands of miles beyond the Moon over the course of an approximately three-week mission. Mission controllers on Earth will collect data to assess the performance of both spacecraft. This mission will also deploy 13 CubeSats that will conduct new scientific investigations and new technology demonstrations that will engage a broader set of universities and companies in lunar exploration than ever before on a single mission.

With the first crewed flight test of the SLS and Orion, Artemis II, astronauts will return to the vicinity of the Moon for the first time in more than 50 years. This will be an Apollo 8 moment for a new generation. At the end of this mission, NASA intends to have tested every hardware, software, and operational component of Artemis III *except* for the actual landing on the surface.

Artemis III will be the culmination of the rigorous testing and nearly one million miles of flight demonstrations on the deep space transportation systems that NASA will accumulate during Artemis I and II. When Artemis III lands the first woman and next man on the Moon in 2024,

America will have demonstrated a new level of global space leadership. With this robust lunar exploration capability re-established, NASA and the world will focus on building a sustained presence on the lunar surface in preparation for long-term development on the Moon and the human exploration of Mars.

The Gateway will establish U.S. leadership and a sustained presence in the region between the Moon and Earth. The platform will offer astronauts easier crew returns, a safe haven in the event of an emergency, the ability to navigate to different orbits around the Moon and later, an advancement in human life support systems.

Gateway will expand to include critical contributions from international partners, specifically, a robotic arm, substantial additional habitation volume, and refueling capabilities. Canada announced in February 2019 that it intends to participate in the Gateway and contribute advanced external robotics. In October 2019, Japan announced plans to join the United States on the Gateway with contributions to habitation components and logistics resupply. In November 2019, the European Space Agency received authorization and funding to support its planned contributions to the Gateway, the International Habitat (I-Hab), and the European System Providing Refueling Infrastructure and Telecommunications (ESPRIT), both of which will dramatically enhance the capabilities of Gateway, contributing to sustainable operations while paving the way for a future human mission to Mars. Russia has also expressed interest in cooperating on the Gateway via the contribution of an airlock. The Gateway will provide a next-generation deep space platform from which to conduct science investigations outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigations to conduct on the Gateway. The first two Gateway payloads are a radiation instrument package provided by the European Space Agency and a space weather instrument from NASA. The agency also recently awarded the first Gateway Logistics Services (GLS) contract to SpaceX to deliver cargo, experiment and other supplies to the outpost. Echoing the success of the Commercial Resupply Services program, GLS will leverage commercial partners to deliver logistics to the Gateway, supporting lunar operations while building experience and technologies for future logistics missions that can support the first human mission to Mars.

With these core elements, logistics support, and flights of SLS/Orion underway, and the acquisition of HLS in progress, NASA is opening up other core elements of a sustained lunar presence – including the lunar terrain vehicle (LTV), the lunar mobile habitat or habitable mobility platform, the lunar foundation surface habitat (FSH), power systems, lunar ISRU systems, and expanded Gateway habitation capabilities – with new international and industry partnerships. With this approach, NASA will leverage years of hard work and national investment in the systems needed to return to the Moon, while enabling and using new partners and new capabilities to ensure that our return to the Moon is sustainable and leads directly to the first human mission to Mars.

ARTEMIS AFTER 2024

After Artemis III, the overall plan is to conduct operations on and around the Moon that help prepare us for the mission durations and activities that we will experience during the first human mission to Mars, while also emplacing and building the infrastructure, systems, and robotic

missions that can enable a sustained lunar surface presence. To do this, we will develop Artemis Base Camp at the South Pole of the Moon.

Artemis Base Camp will be our first sustainable foothold on the lunar frontier. We will initially move to one to two-month stays to learn more about the Moon and the universe. We will develop new technologies that advance our national industries and discover new resources that will help grow our economy. Overall, the base camp will demonstrate America's continued leadership in space and prepare us to undertake humanity's first mission to Mars.

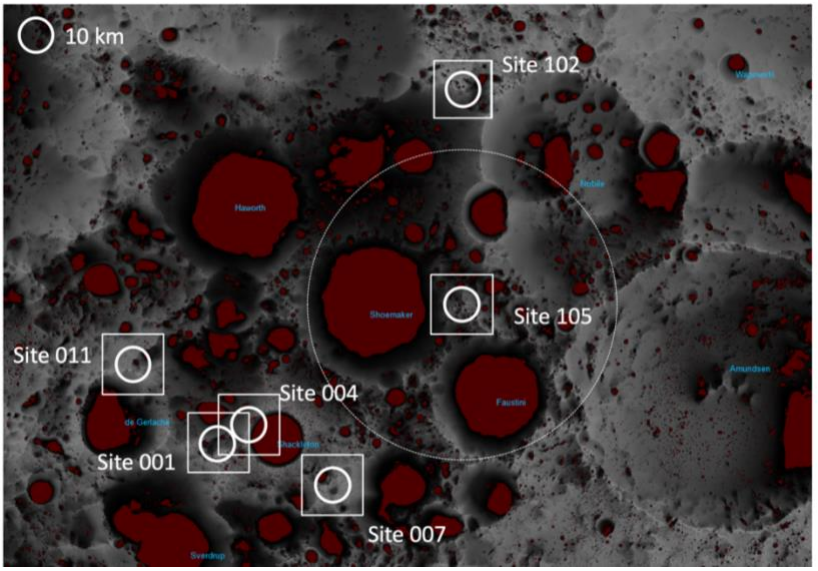


Figure 5: A South Pole landing site has not been determined, but this image shows sites of interest near permanently shadowed regions, which may contain mission-enhancing volatiles. These sites may also offer long-duration access to sunlight, direct-to-Earth communication, surface slope and roughness that will be less challenging for landers and astronauts.

The three primary mission elements of Artemis Base Camp are: The LTV that can transport crew around the site; the habitable mobility platform for long-duration trips away from Artemis Base Camp and the foundation surface habitat will enable short-stays for four crew on the lunar South Pole. Combined with supporting infrastructure added over time such as communications, power, radiation shielding, a landing pad, waste disposal, and storage planning – these elements comprise a sustained capability on the Moon that can be revisited and built upon over the coming decades.

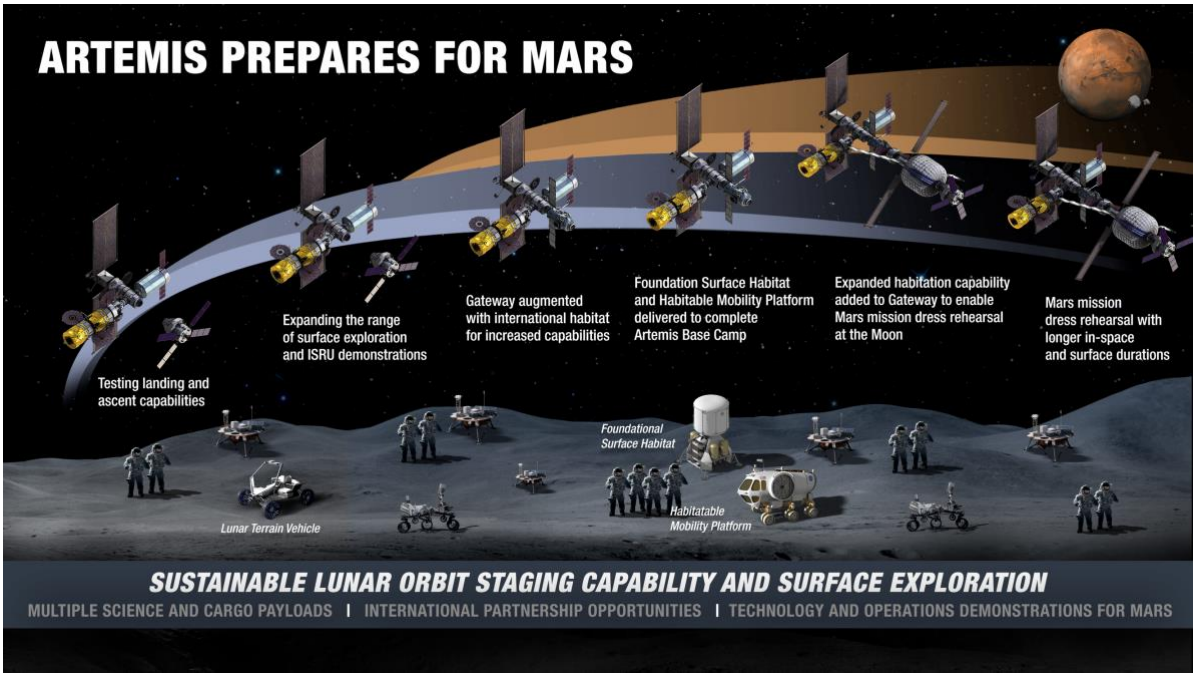


Figure 6: Artemis Base Camp evolves on the surface as the Gateway is leveraged for Mars preparation.

Mobility is a major part of the Artemis Base Camp. The LTV and the habitable mobility platform will enable long-term exploration and development of the Moon. In addition to its size, the Moon's geography is complex, and its resources dispersed. Looking at potential sites for Artemis Base Camp, such as near Shackleton Crater, shows the immense scale of the lunar geography. Robust mobility systems will be needed to explore and develop the Moon. The same is true for Mars, making the habitable mobility platform a particularly important element as we will need a similar type of vehicle to explore the Red Planet.

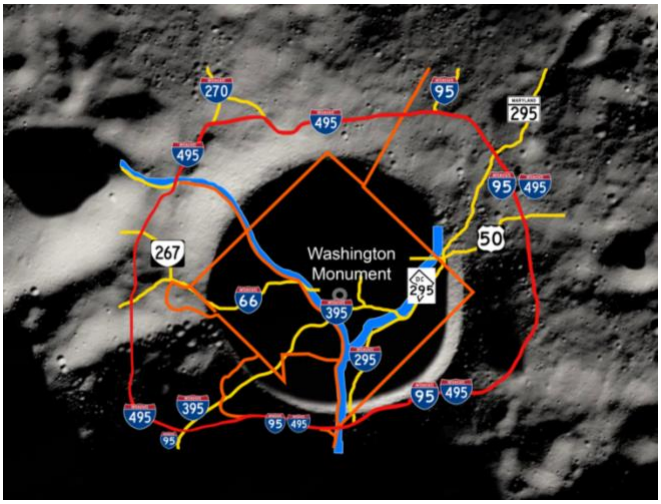


Figure 7: The lunar South Pole's Shackleton Crater, as captured by the Lunar Reconnaissance Orbiter, with the Capital Beltway overlaid for scale.

In addition to establishing Artemis Base Camp, another core element of the sustained lunar presence that feeds forward to Mars will be the expansion of habitation and related support systems at the Gateway. This evolution of the Gateway's systems to include large-volume deep space habitation would allow our astronauts to test, initially in lunar orbit, how they will live on their voyage to and from Mars. Gateway can also support our first Mars mission analogs on the lunar surface. For such a mission, we currently envision a four-person crew traveling to the Gateway and living aboard the outpost for a multi-month stay to simulate the outbound trip to Mars, followed by two crew travelling down to and exploring the lunar surface with the habitable mobility platform, while the remaining two crew stay aboard. The four crew are then reunited at the Gateway for another multi-month stay, simulating the return trip to Earth, before landing

Figure 8: Orion approaches an evolved Gateway.

back home. These missions will be by far the longest duration human deep space missions in history. They will be the first operational tests of the readiness of our long-duration deep space systems, and of the split crew operations that are vital to our approach for the first human Mars mission.

There are many factors associated with the sequence of element development, testing, and launch such as capability maturity and availability, budget, launch vehicle availability, and system complexity. For planning purposes, NASA is developing a sequence that accounts for these variables and results in an annual cadence of demonstrable progress and a gradual increase in mission duration and complexity. This plan results in the development and emplacement of the infrastructure required for a long-term sustained lunar surface presence while testing systems and gaining the operational experience required for the human Mars mission.

The sequence as currently envisioned begins by sending lunar precursor robotic missions including VIPER by CLPS landers to provide ground truth of terrain, as well as water and metal resource availability for the human lunar landing site. To provide mobility and extended range of exploration for the first several human lunar surface missions, the LTV will be delivered to the lunar surface. The first elements of the lunar Gateway are in development and will support later sustainable human lunar landing missions. NASA anticipates its international partners will provide at a minimum the robotic arm, I-Hab, and ESPRIT to supplement the Gateway's capabilities in lunar orbit.

The habitable mobility platform will be delivered to the lunar surface to expand our exploration range by tens of kilometers and mission duration on the surface from 7 days to 30-45 days, enabling potential Mars surface analog missions on the lunar surface. Other key pieces of the Artemis Base Camp infrastructure are also delivered, including the foundation surface habitat, which will support a crew up to four on the lunar surface, the lunar surface power systems, ISRU demonstrations and pilot plants.

An evolved Gateway habitation capability in lunar orbit will allow us to begin the methodical lengthening of mission durations. This approach will also allow NASA to test risk mitigation approaches for long-duration mission crew and element systems risks that are required for two-year Mars class missions.

Once these pieces of the Moon to Mars campaign are delivered and operational, annual human missions with increasingly long durations will enhance the exploration and sustainable development of the lunar surface.

A VIBRANT EARTH-MOON FUTURE

Whenever the first human mission to Mars occurs, it will not mean that we are done with the Moon. The windows for launching the two-year mission to Mars open up every few years, and we will continue to conduct human missions to the lunar surface to test systems, conduct scientific investigations, and continue to develop our sustainable lunar presence as we prepare for the optimal launch window.

We will continue to explore the Moon indefinitely -- leveraging robotic deliveries provided by CLPS providers, longer duration human missions, and commercial and international

partnerships that will add to the Artemis Base Camp elements NASA puts in place. The LTV, habitable mobility platform and foundation surface habitat will stay on the Moon enabling crews to live on the lunar surface for months at a time. The rovers and crew-tended capabilities on the Moon will be designed to operate autonomously and to work with independent robotic assistants.

In addition to testing our systems for the first mission to Mars, a core purpose of Artemis Base Camp will be to demonstrate new technologies that, over time, will expand our capabilities and reduce the costs of lunar operations. Astronauts at Artemis Base Camp will be testing a wide set of new technologies in six priority areas encompassed by the recently announced Lunar Surface Innovation Initiative (i.e. ISRU; surface power; extreme access; excavation and construction; lunar dust mitigation; and extreme environments*)*. Some of these technologies will help from the beginning, such as lunar dust mitigation and enabling operations in extreme environments like the cold of the lunar night. Other technologies are in early development for significant long-term benefits. For example, ISRU will enable the production of fuel, water, and/or oxygen from local materials, enabling sustainable surface operations with decreasing supply needs from Earth. For surface power, our goal is to develop advanced solar collection and a small, lightweight fission power system to support even longer-duration missions and operations on the Moon, and eventually for Mars and beyond. Autonomous manufacturing, excavation, and construction technologies will make infrastructure emplacement more affordable.

Astronauts will also conduct tests of advanced robotics, including future biomimetic systems that enable more autonomous operations at the Moon and can serve as robotic assistants to the crew. In time, Artemis Base Camp might also include a hopper that could deliver science and technology payloads all over the Moon and which could be operated by crew at Artemis Base Camp and refueled using locally sourced propellant. A lunar far-side radio telescope could also be remotely emplaced and operated from Artemis Base Camp – a sort of backyard radio-telescope at our first encampment on the Moon.

Developing a sustained and vibrant lunar presence will not only require the best of NASA and its international partner space agencies, but also the best of the entire U.S. government and commercial sector. Establishing the infrastructure that will enable additional international and commercial partnerships will result in opportunities for the first international and commercial astronauts on the lunar surface, opening up Earth's 's off-shore continent for ongoing human discovery and development. NASA's unique leadership and capabilities will be combined with innovation and contributions from the same sectors that fuel our nation and economy here on Earth.

THE INITIAL HUMAN MARS MISSION

The success of the first human mission to Mars requires a voyage of stunning technological and operational complexity. The distance from Earth to the Moon is a relatively manageable 250,000 miles. In contrast, Mars is, on average, 140 million miles from Earth. The challenges of a mission to Mars are compounded not only by these distances but by the more dangerous levels and types of radiation that is found in deep space. Mars' atmosphere – while intriguing from a scientific perspective – also presents distinct challenges for getting humans to and from its surface.

The initial lunar missions will greatly inform our concept of operations for Mars. Every day in deep space increases the probability of catastrophic events occurring. The concept of operations NASA is working toward for the first human mission to Mars is therefore one that reduces trip time significantly and minimizes time spent on the surface to around 30-45 days. Factors NASA will continue to consider include: risks to crew health during transit, both from galactic cosmic ray (GCR) radiation and from potential catastrophic mission events; the complexity of mission operations on the Martian surface; and the complexity and cost of mission systems, such as in-space propulsion, the ability to land heavy payloads, and required surface systems. NASA has targeted conducting a human mission to Mars that can be realized as soon as possible, while still ensuring that our Mars surface capabilities will allow for extensive exploration on our first mission, including a search for Martian life. The Moon will allow us to test and demonstrate significant parts of this mission before sending humans on this epic journey. NASA will have more to share on the strategy for how the Moon prepares us for the first human mission to Mars in the coming months.

Artemis and the development of Artemis Base Camp will inspire the world with the ability and commitment of American leadership, and in the positive potential of humanity as a whole. If we are to leave a legacy of greatness, hope, limitless opportunity, and growth to future generations, then it is a mission we cannot afford to postpone.