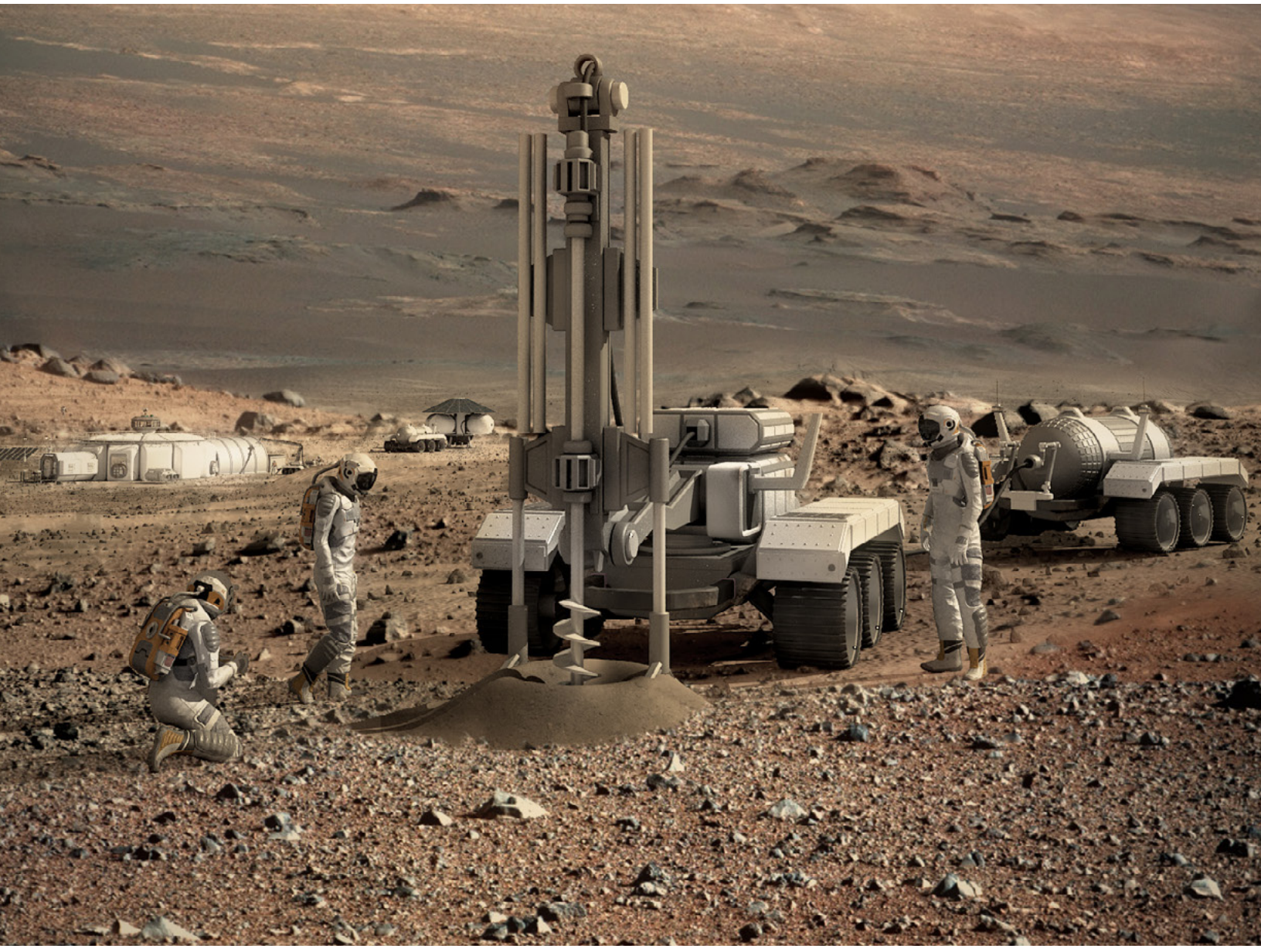
THE HUMANS TO MARS REPORT 2019

AN **EXPLORE MARS, INC.** PUBLICATION



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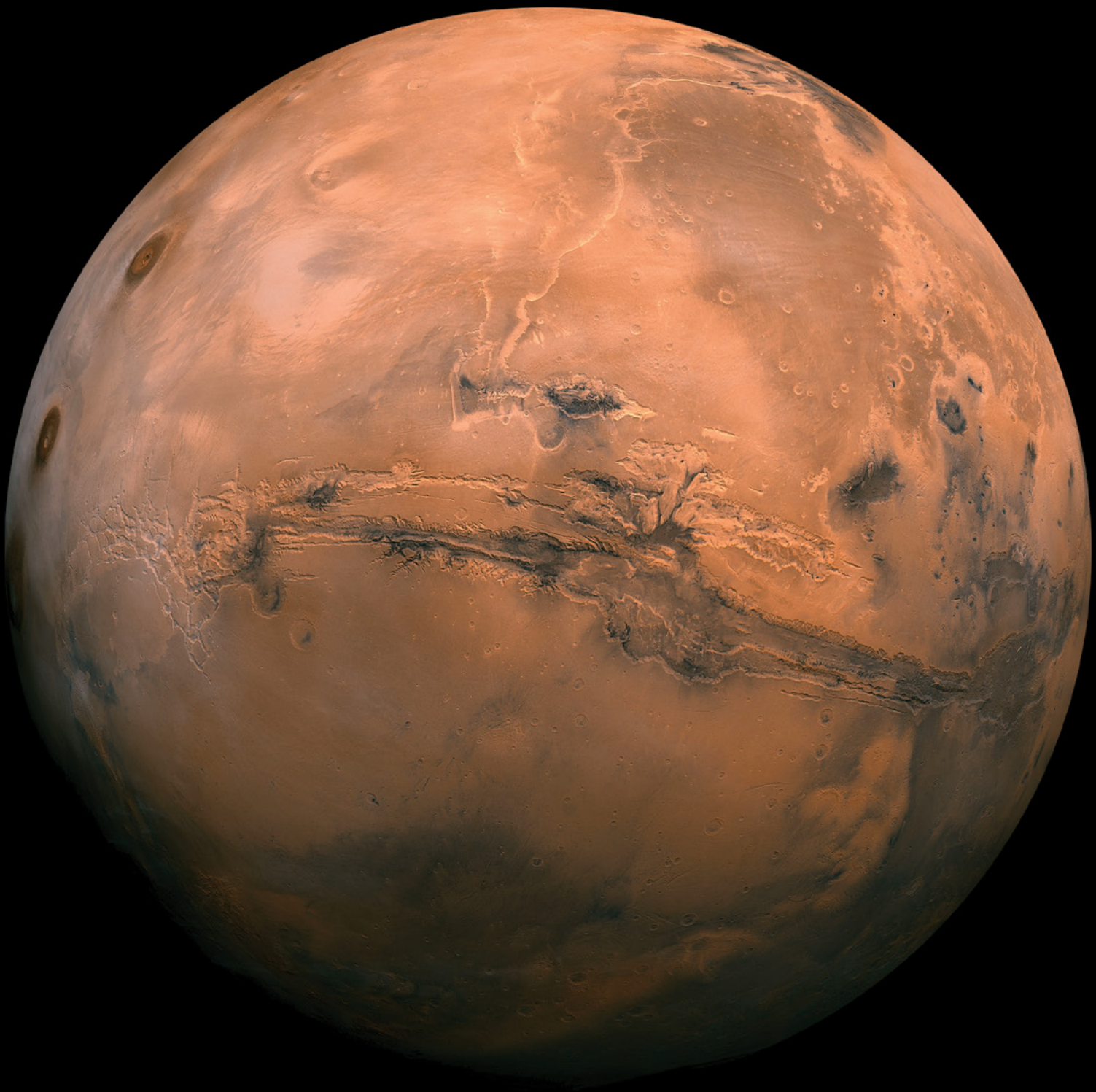

The HUMANS TO MARS Report 2019

Landing Humans on Mars by 2033

The Humans to Mars Report (H2MR) is an annual publication that presents a snapshot of current progress in mission architectures, science, domestic and international policy, human factors, and public perception regarding human missions to Mars - and highlights progress and challenges from year to year. By doing so, H2MR provides stakeholders and policy makers with an invaluable resource to assist them in making decisions that are based on current facts rather than on the dated information and speculation that sometimes tends to persist in the public arena where Mars is concerned.

H2MR does not advocate any particular approach to getting to Mars, nor will this report address speculation or rumor about future architectures - except when such are impacting public perception and policy decisions.

The past year has been a particularly active year with regard to space policy. The National Space Council announced that it is now the goal of the United States to return humanity to the Moon by the year 2024. According to NASA Administrator Jim Bridenstine, this will help enable human missions to Mars by 2033, as required by the *NASA Transition Authorization Act of 2017*. This is essential as Mars exploration maintains broad-based bi-partisan support, with unwavering support coming from NASA, Congress, and industry. Public interest in Mars also remains strong, as evidenced by recent public polling. Although a recent report argued that missions to Mars in 2033 may not be feasible under certain conditions, we maintain that if the United States adopts leaner architecture approaches than those assumed in that report and if both funding and political capital are applied to the new accelerated space policy, humans on Mars in 2033 remains an achievable goal.

As always, through the publication of the *Humans to Mars Report*, Explore Mars is not discounting the prospect of human exploration of other destinations in the solar system. In fact, as with lunar exploration, we embrace them, as long as they do not significantly delay human missions to Mars. We view Mars as a critical destination that will enable the exploration and development of space – and we firmly believe that humanity should set the goal of sending humans to Mars by 2033.

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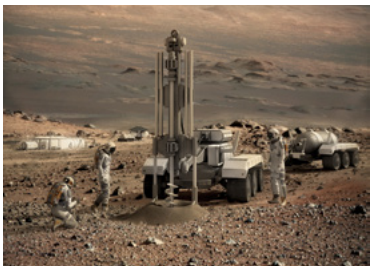

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Explore Mars, Inc.

Explore Mars was created to advance the goal of sending humans to Mars within the next two decades. To further that goal, Explore Mars conducts programs and technical challenges to stimulate the development and/or improvement of technologies that will make human Mars missions more efficient and feasible. In addition, to embed the idea of Mars as a habitable planet, Explore Mars challenges educators to use Mars in the classroom as a tool to teach standard STEM curricula.

Explore Mars, Inc. is a 501(c)(3) non-profit corporation organized in the Commonwealth of Massachusetts. Donations to Explore Mars are tax-deductible. You can contact us using our website https://exploremars.org or at the email address info@ExploreMars.org

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INTRODUCTION

The immeasurable benefits that our space program brings to our economy, our prosperity, and our national security have long been recognized. This is reflected in the strong support that exists in the political realm, among the general public, and elsewhere for achieving the goal of humans walking on the surface of Mars in the 2030s. The momentum that has been building for many years to send humans to Mars has continued unabated, and indeed has grown, during the past year.

With the enactment and signing into law in March 2017 of the *NASA Transition Authorization Act of 2017*, the legislative and executive branches of government reaffirmed their bipartisan commitment to expand human presence beyond low Earth orbit, with the aim of launching a human spaceflight mission to Mars by the year 2033. This is a goal and time frame that has been advocated by Explore Mars, Inc. for many years. Shortly thereafter, in June 2017, the National Space Council was created by Executive Order, and the President issued Space Policy Directive #1 (SP1) in December 2017, both of which placed a greater short-term emphasis on the utilization of the Moon. Then, in March 2019, at the 5th meeting of the National Space Council, Vice President Mike Pence announced that it is now the stated policy of the United States to return to the Moon by the year 2024. However, no changes have been made to United States policy to send humans to Mars, as was made clear by NASA Administrator Jim Bridenstine at that same meeting.

Over the past year, much has transpired with respect to robotic missions, including the successful touchdown on Mars of the InSight lander in November 2018. In addition, work has continued to prepare the Mars 2020 rover for launch. Such robotic missions are necessary precursors to future human missions. However, our aging fleet of Mars orbiters will require replacement in the near future, and a Mars Sample Return mission is also considered to be a top priority for the 2020s. These robotic missions will maximize scientific goals, as well as advance human exploration in the 2030s.

Progress on mission architecture concepts and refinements has also continued over the past year within NASA, in academia, and in industry. These concepts have placed particular emphasis on addressing commonalities among the various architectural approaches and concepts, as well as the many “long pole” technologies that must be developed in order to send humans to Mars. In addition, thanks to such efforts as the *Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars* (AM VI) that was held in Washington, DC in August 2018, an important dialogue has begun involving the lunar and Mars communities to critically assess how operations, technologies, and facilities for the Moon and its vicinity might feed forward to astronaut missions to the martian surface.

Exciting work is also being performed on the “human factors” associated with deep space missions, in order to mitigate overall risk to astronauts. These include research on the effects of long-term exposure to radiation and microgravity as well as studies on an advanced food technology portfolio that are underway to examine nutrient degradation in foods stored under different environmental conditions.

Finally, the fascination of the general public for human missions to Mars is perhaps best evidenced by the extensive and growing number of Mars exploration themes that continue to appear in the media, in the entertainment industry, and even in consumer products.

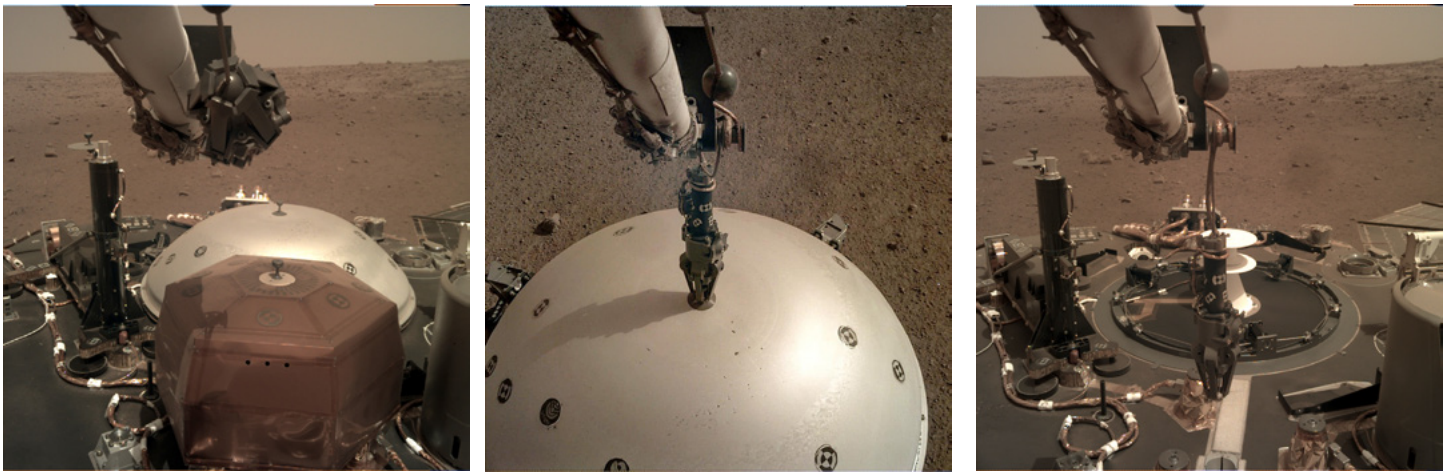
The goal of walking on Mars has always held a special place in the collective consciousness of all humanity. We can now achieve that goal in less than two decades. As was once correctly said about the Moon and can now be said about Mars: We only have to make the decision to go there.

MARS SCIENCE and RECONNAISSANCE

Paving the Way for Human Exploration of Mars

As plans for human exploration to the Moon and Mars begin to accelerate, the United States and its partners are already preparing for precursor robotic science missions that are critical first steps to sending humans to Mars. International participation in Mars science missions has also been increasing and will reach its highest peak thus far in 2020 when the United States, Europe, the United Arab Emirates, and China will be launching missions to Mars orbit and its surface.

Numerous important scientific discoveries and reconnaissance advances were made during the past year at Mars as the world prepares for an unprecedented number of Mars missions in 2020 and the following decade.



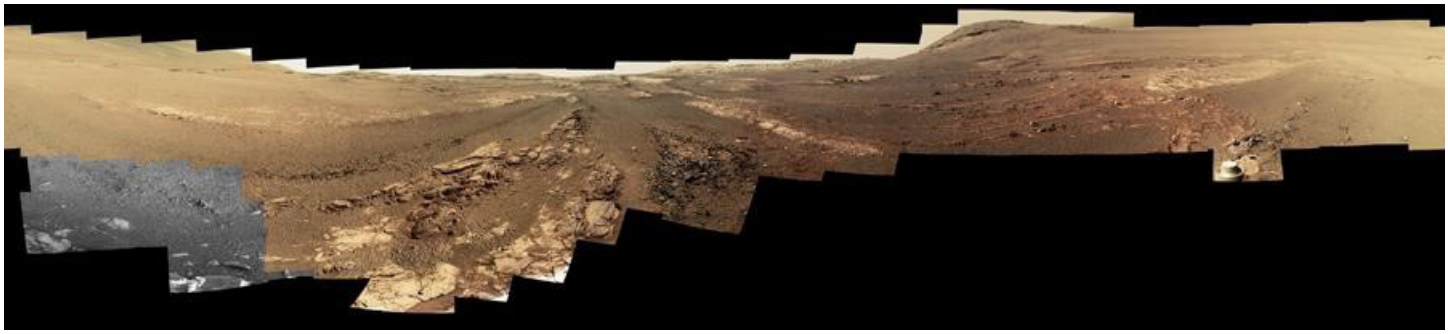
The instruments on InSight as well as the view from its landing site in Elysium Planitia (via the ICC camera, courtesy NASA/JPL)

Most Publicized New Stories

InSight's Successful Landing and Preparation to Reveal Mars' Interior

With the successful landing of the *InSight* (INterior exploration using Seismic Investigation, Geodesy, and Heat Transport) geophysical/meteorology probe on Mars in November 2018, experiments have begun in the process of characterizing the interior of Mars by means of extremely sensitive seismometry and heat-flow measurements and comparing it with other rocky planets. As of spring 2019, Insight's seismometer and heat-flow probe have deployed and the spacecraft has already returned evidence of the first "likely Marsquake". It has also begun using its "Mole", a percussive drill that is designed to reach a depth of 3-5 meters below the surface[1], which is a key part of the Germany-provided Heat flow sensor (HP3). If successful, this drill will reach the deepest depth ever drilled on Mars. In addition to science, this instrument serves as a key technology demonstration for future missions looking to access and characterize subsurface ice on Mars, which is critical for human exploration and astrobiology.

In addition, the MarCO cubesats, small twin communications-relay satellites that launched as a secondary payload with *Insight*, successfully communicated with Earth from the vicinity of Mars and provided real-time relay and telemetry during Mars Insight's landing operations – data that would have otherwise taken hours to arrive back on Earth. The MarCO mission was the first cubesat mission to ever visit another planet. Its success demonstrates that future small missions have the potential to make meaningful contributions to science and reconnaissance objectives at a much lower cost and development time as compared to traditional missions.



This panorama of 354 images taken in Endeavor Crater represents some of the last photos captured by Opportunity before it lost power

The Celebration of Opportunity's Long and Fruitful Mission

Humanity lost a highly successful and valued member of our fleet of assets at Mars in early 2019 during a global dust storm. The Opportunity rover was unable to use its solar panels to recharge its batteries during a dust storm that blocked out the Sun for four months (peaking in July 2018). After traveling over 45 kilometers on the Martian surface during 15 years of operation and making innumerable scientific discoveries, *Opportunity* greatly expanded our understanding of past and present water (as recorded in the rock record) on Mars. NASA officially declared Opportunity's mission complete on February 13, 2019. Opportunity survived well beyond its original 90-day mission and paved the way for future robotic exploration of the red planet. Human Mars mission planners should keep the lessons of these dust storms in mind when deciding on the surface power infrastructure for human outposts on Mars – solar power will most likely not be sufficient by itself.

Subsurface Lake on Mars

In July 2018, researchers announced that they found evidence of a potential body of liquid water that lies ~1.5 kilometers under the planet's south polar ice cap. They made this discovery using MARSIS, a multi-frequency MHz radar sounding instrument aboard the European Space Agency's (ESA) Mars Express orbiter. This exciting discovery of a radar scattering behavior that can be interpreted as saline water (in a lake) offers optimism for preserved pockets of sub-surface liquid water on Mars. Data from shallow radar sounding by MRO's SHARAD has yet to confirm the Mars Express MARSIS detection.

Updates from Mars Orbit and Surface

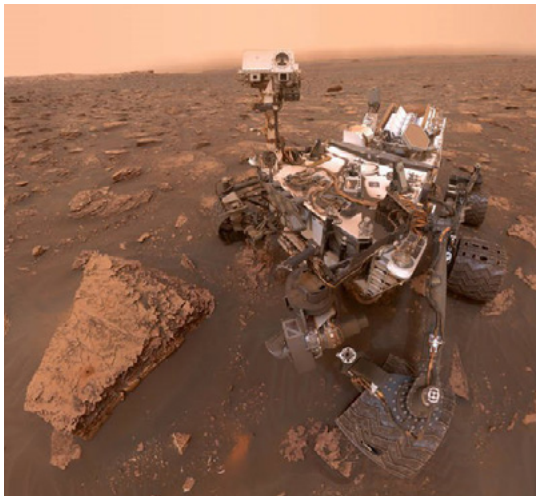
An international fleet of Mars science robots remains at work on and around Mars. These include:

Curiosity Rover

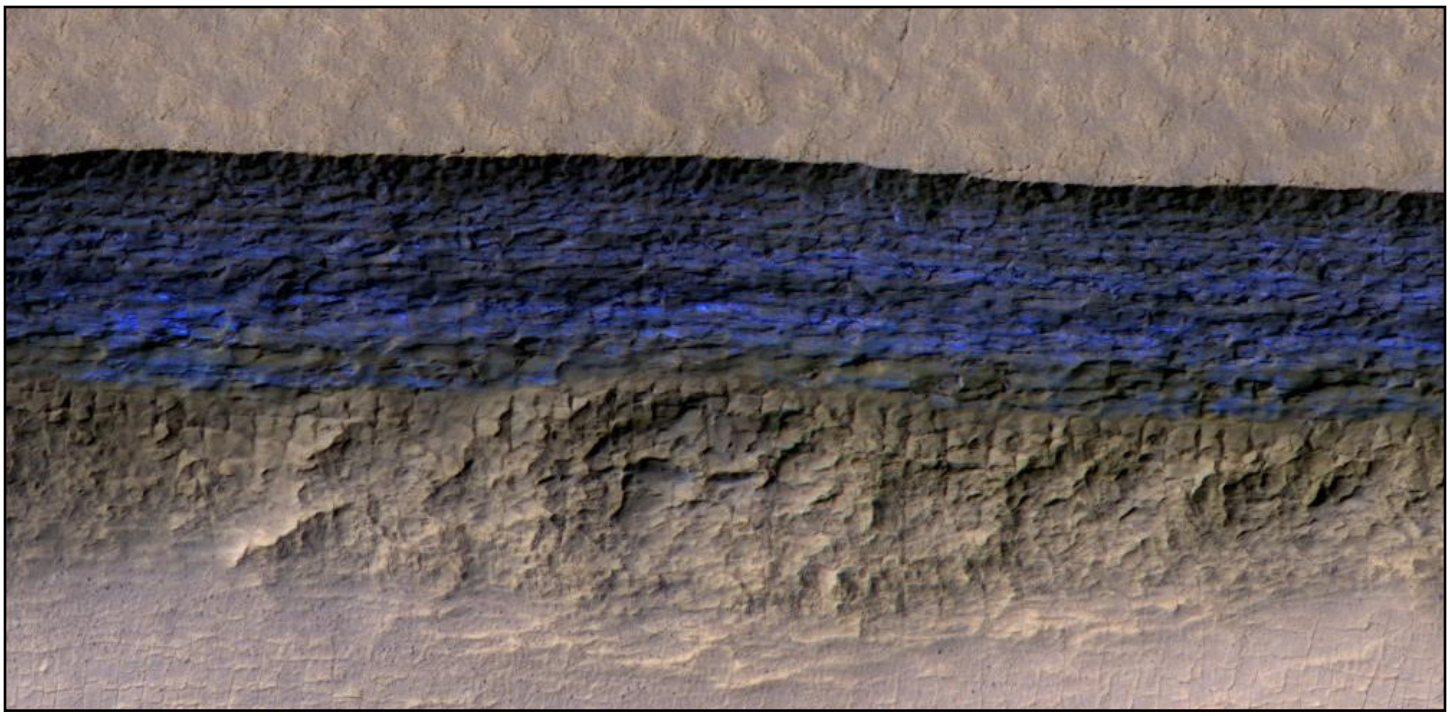
The Mars Science Laboratory *Curiosity* rover continues to rove after 6-plus years and 20 kilometers of exploration on the Martian surface within Gale Crater. Curiosity has made major contributions to both science and reconnaissance at Mars.

Some recent discoveries include:

- Gale Crater intermittently had a series of lakes fed by rivers and ground-water, with activity spanning millions of years. The rover is now in the "clays" unit as defined from orbit, having finished its exploration of Vera Rubin Ridge with its varying hematite mineral signatures.
- Detection of a diversity of organic molecules in several drilled samples. Although these molecules are not direct evidence of life, they can be produced via biological processes.
- Indications of seasonal variations in atmospheric methane. Both biological and geological processes can produce atmospheric methane. Further study will be required to determine the origin of these detections.
- Validation of orbital detections of hydrated minerals, a potential water feedstock for future human missions, and a key part of the "water story" on Mars in the rock record.



Curiosity's view of Gale Crater during the 2018 global dust storm (courtesy NASA/JPL/MSSS/MAHLI)



Exposed Ice Scarp at 56.6 degrees south latitude. This section of nearly pure water-ice is more than 100 meters tall.

U.S. Orbiters

The discoveries from the MAVEN (Mars Atmosphere and Volatile EvolutioN) mission, the Mars Reconnaissance Orbiter (MRO), and Mars Odyssey continue to stimulate a more intensive examination of Martian climate history and the role and states of water in the Martian system over geologic time (as well as how Mars' atmosphere interacts with the solar wind).

Some recent discoveries from NASA's Mars orbiters include:

- Warmer, wet periods lasting millions of years occurred on ancient Mars, with episodic water activity as recently as 2.3-3.5 billion years ago.
- Abundant carbonate detected in many Noachian Epoch rocks increases evidence for a massive early atmosphere and of habitable environments.
- Near-surface water ice was detected in more locations, including exposed 100-meter-tall ice-bearing cliffs in high mid-latitudes, while new, higher-resolution maps from the Odyssey Neutron Spectrometer suggest low-latitude locations of water, including as hydrated minerals.
- Water vapor (hydrogen) is transported to the upper atmosphere during the dusty season and in large dust events, increasing hydrogen escape by a factor of 10 during regional dust storms.
- *Recurring Slope Lineae* (RSL) appear to be more like dry flows as opposed to briny liquid water flows as previously thought. The mechanism behind these flows is not yet understood, and the presence of liquid water in this process has not been ruled out. Further study is required to understand the origin and frequency of RSLs, perhaps involving new orbital techniques or landed access.
- MRO continues to detect new impacts bringing the current total to 600 impacts detected over the last decade, some exposing ice at depth. Ice-exposing impacts are key for confirming the existence of subsurface ice deposits within the uppermost 10-15m of the surface.
- Atmospheric loss to space is a major driver of Mars' climate evolution.
- Argon isotopes indicate loss of 2/3 of the original atmosphere via the loss of uncharged atoms/molecules.
- The magnetosphere today is rarely in steady state; solar events drive variability while crustal magnetic fields influence densities and temperatures in both the day and night-side ionosphere.

A 5-meter meteoroid impact in a crater wall and the ensuing kilometer-long avalanche of regolith as captured by HiRise

European Orbiters

Two European-led Mars orbiters have also expanded our understanding of the red planet. After 11 months of aerobraking, the ExoMars Trace Gas Orbiter (TGO) began its science activities in April of 2018. Recent reports indicate that TGO failed to detect methane, which conflicts with local findings from the *Curiosity* rover and Mars Express missions. TGO has also begun developing improved resolution maps of hydrogen detections using its Fine Resolution Epithermal Neutron Detector (FREND) instrument. TGO with its NASA-provided Electra UHF relay package has bolstered the Mars Relay Network and is currently returning more than half of the total data downlinked from Curiosity and the InSight Lander.

ESA's Mars Express continues its Mars orbital mission. Most significantly, as indicated in this report previously, by observing MHz frequency radar bright reflections from 1.5 kilometers beneath the base of the south polar cap, Mars Express deduced that a briny, subsurface lake many miles in length may exist in this region at tens of km scales.

India Mars Orbiter Mission

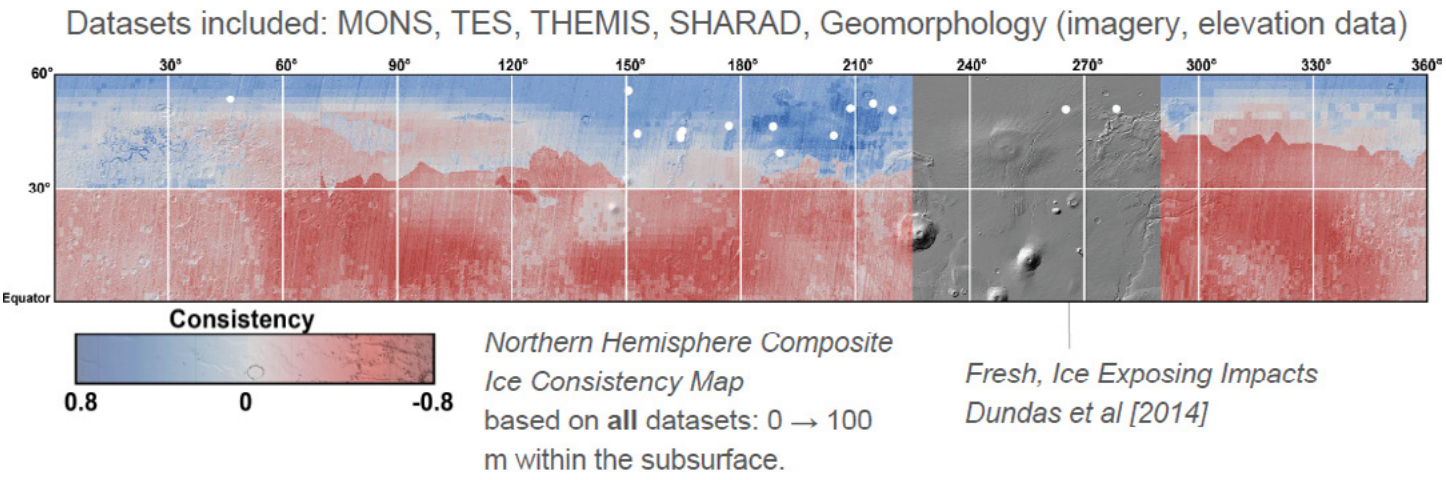
The Indian Mars Orbiter Mission (MOM) reached its fourth year in orbit around Mars in September, well beyond the designed mission life of six months. MOM has provided images of both Martian moons, including the back-side of Deimos (the part facing away from Mars). The orbiter also characterized neutral and ionic molecules in the extended Martian atmosphere. The first 3 years of data are now available publicly with more imagery and atmospheric study to follow.

Mars Colour Camera aboard MOM captures water-ice clouds above Olympus Mons

Other Reconnaissance News

In 2018, NASA commissioned two sets of teams to create next generation maps of both subsurface ice and hydrated mineral deposits across Mars by means of creative utilization of existing mission data.

One team is combining existing data sets in innovative ways to bridge the knowledge gaps around subsurface ice water deposits on Mars. The Subsurface Water-Ice Mapping (SWIM) team made significant progress towards developing maps of subsurface ice across the northern hemisphere of Mars. Their work will help inform how a next-generation orbiter should prioritize its observations, where a special regions drill designed to access subsurface ice might land, and where the first human outpost might be located. Ultimately a new Mars orbiter carrying a polarimetric synthetic aperture radar will be required to refine these observations and determine how far these deposits extend towards the equator, and at what depth they can be accessed.



More information and preliminary results can be found at: https://swim.psi.edu

Two other teams are developing next-generation global maps of hydrated minerals with the highest potential for exploitation by future human crews. Both teams will process hundreds of thousands of spectra collected by the MRO Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) and the Infrared Mineralogical Mapping Spectrometer (OMEGA) instruments. Once complete, the two maps will be compared to build confidence in the presence and extent of attractive hydrated mineral deposits that may guide human landing site selection.

2020: The Year of International Mars Science Missions

A convoy of international science missions will head to Mars in 2020. This includes missions led by the United States, the European Space Agency, and the United Arab Emirates. These missions have the potential of dramatically impacting our understanding whether Mars had past or present life.

- The Mars 2020 rover is on schedule for a July 2020 launch. By means of the same general design as the Mars Science Laboratory (MSL), the 2020 rover will search for chemical evidence of past life on Mars and cache diverse rock and soil samples that will later be retrieved by a lander with a "fetch" rover as part of a potential Mars Sample Return campaign in the late 2020's. This mission will also carry an ISRU (in-situ resource utilization) demonstration experiment (Mars Oxygen In situ resource utilization Experiment, or MOXIE) to commence engineering evaluation and validation of strategies to produce oxygen from Mars' carbon-dioxide atmosphere. This demonstration will help mission planners understand how future explorers can "live off the land" by using natural resources on Mars, enablers of sustained human settlement in the future. Furthermore, it will carry a Norwegian ground-penetrating radar (RIMFAX) with the potential to detect shallow ice layers at its Jezero crater landing region at the finest possible scales.

- The ExoMars rover "Franklin" and surface platform is also scheduled to launch in 2020. This mission will probe the near-subsurface and drill down one meter for material to be analyzed onboard. The rover's rotary drill will teach us about the technologies necessary to access subsurface ice on Mars. ExoMars Franklin will be searching for evidence of life on Mars utilizing the Pasteur payload and joint US/Germany molecular analyzer (MOMA-MS), the first biosignature exploration instrument capable of uniquely recognizing biogenic organic molecules on Mars.

These two mobile surface laboratories (NASA's Mars 2020 and ESA's ExoMars Franklin 2020) will provide much needed scientific and engineering information to inform key development decisions that will ultimately enable human exploration of Mars.

- The Chinese space agency has announced plans to launch a combination orbiter and rover mission to the Martian system in 2020. The orbiter and solar-powered rover, which will land at either Chryse Planitia or Isidis Planitia, will study Martian geology, characterize surface materials, and investigate the Martian atmosphere and magnetosphere.

- Marking the 50th anniversary of the independence of the UAE, the *Hope* orbiter mission is also scheduled to launch in 2020. The Hope orbiter will assume a high, nearly areo-stationary orbit. Over the course of its two-year primary science operations it will study Martian weather to better understand long-term atmospheric loss, the history of Martian climate, and seasonal changes in the atmosphere. The UAE views this mission not only as an opportunity to accomplish science objectives, but also to encourage more participation in Science, Technology, Engineering, and Mathematics (STEM) and to integrate with the international Mars community.

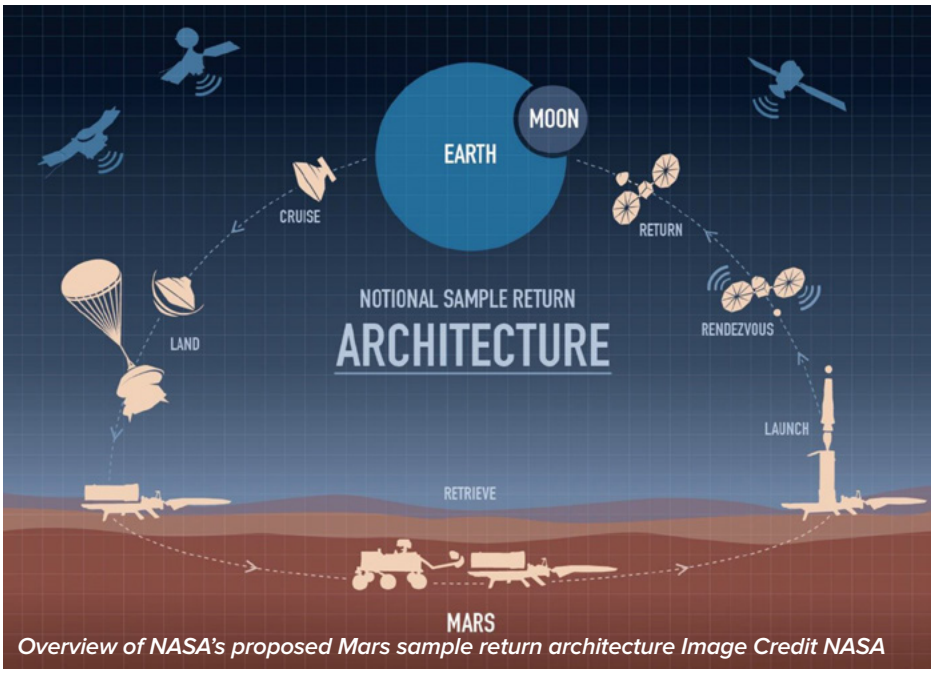
Looking Ahead

Despite the remarkable success cited above, due to budgetary and political constraints, the plans for developing and launching required robotic missions following the Mars 2020 Rover is far from assured. No United States-led Mars science missions are currently approved beyond 2020.

Mars Sample Return

A Mars Sample Return campaign is a critical science mission that would also serve as the first demonstration of a round-trip mission to Mars, including a launch from the Martian surface. By returning samples, it would provide reconnaissance results essential to enabling human visitations to the surface of the Red Planet in the early 2030s. In addition to providing a better understanding of the possibilities for past life on Mars, a Mars Sample Return would greatly increase our scientific knowledge of the Martian regolith. It would enable us to characterize the mechanical properties of the regolith/dust (abrasiveness, oxidizing potential particle size, etc.) and potential human health hazards (toxicity, respiratory, extant life, etc.). This information would help define both science objectives and technology design for future human missions.

A Mars Sample Return campaign has been building international support over the past few years. During the spring of 2018, a special workshop was held in Berlin, Germany to discuss the prospects of an international Mars Sample Return mission. ESA and NASA signed a statement of intent "to jointly develop a Mars Sample Return plan to be submitted to their respective authorities by the end of 2019." Both agencies will be seeking approval for the campaign in 2019 with the aim to launch potentially as early as 2026. Encouragingly, the FY2020 president's budget request included $109 million to begin formulation of the next steps in a Mars sample return campaign.



Overview of NASA's proposed Mars sample return architecture Image Credit NASA

Mars Resource-Seeking Orbiter

A resource-seeking reconnaissance orbiter is an essential precursor to sending humans to Mars. An orbiter equipped with a polarimetric synthetic aperture radar capable of detecting near-surface ice is necessary to fill key knowledge gaps about potential water resources at Mars in the uppermost 5-10 meters of the Martian surface layer. Such a mission will be critical to inform where future missions will focus the search for life and the viability of subsurface ice to support human operations at Mars (e.g. propellant, consumption, agriculture, etc.). This knowledge will help narrow down the location of the first human base. The results from the subsurface water-ice mapping work discussed above will help this mission prioritize its first regional targets.

Integration

As plans develop to send humans into deep space, better systems of integration need to be developed between NASA mission directorates, industry, and international partners for cost-effective mission planning.

Science has always provided critical information to promote and to expedite human exploration. In her recent review of the Apollo 8 human mission to the Moon, science writer Mary Roach meaningfully stated: "*It was science that got us to the Moon – not just its mastery but a cultural consensus about its importance and worth.*" [Washington Post, April 2018]. The robotic scientific pathfinders of today will follow this precedent and allow humanity to surmount the obstacles presented by voyages to Mars as we plan mission architectures to open its always promising frontiers.

Recommendations:

- Complete a round-trip demonstration mission to the Martian system, which would also accomplish the National Academy of Sciences, Engineering, and Medicine Planetary Decadal Survey's highest priority, Mars Sample Return. The samples would not only achieve revolutionary science, they would also allow scientists to assess the material characteristics of the dust, its potential toxicity to human explorers, and to develop appropriate planetary-protection measures.
- Implement a next generation orbiter as soon as possible to prospect for resources (notably water-ice) that will reduce the overall cost of missions to Mars while providing significant science gains. Even if ISRU is not needed for initial human missions to Mars, such reconnaissance is essential for selecting human landing sites. Such an orbiter is also key to replacing an aging telecommunications infrastructure at Mars.
- Explore the potential of a special regions drill to access subsurface ice deposits on Mars. A spacecraft would need to make chemical assessments of what is in the water for both science and potential human use in advance of the first crewed missions to the surface of Mars. There is growing scientific consensus that these subsurface ice deposits may be among the most likely place to find evidence of life of Mars. These deposits also have potential for In-Situ resource utilization for human crews on the surface.
- Embrace stronger collaboration between NASA mission directorates to assure that the science missions of the 2020s maximize both scientific goals as well as advance human exploration in the 2030s.

ARCHITECTURES AND SYSTEMS
Current Progress of Elements Required for Mars

There is a new sense of urgency this year for sending humans beyond low Earth orbit (LEO) and exploring deep space, as reflected in Vice President Mike Pence's speech at the Huntsville meeting of the National Space Council in March 2019. While the Vice President's speech focused on a return to the lunar surface by astronauts, NASA Administrator Jim Bridenstine has made it clear that the approach used to accomplish this grand goal needs to be a sustainable one that builds toward landing humans on Mars in the 2030s. The concepts described in this section represent a cross section of current approaches and are not intended as endorsed or final solutions. These approaches demonstrate that, given a sustained effort devoted to human exploration, it is feasible to envision the first crewed missions to Mars in the 2030s. At the same time, a sustainable architecture supporting exploration and eventual commercial exploitation of lunar resources will be put in place.

The following sections describe NASA's concepts and process for exploring Mars, provide updates on industry progress, and summarize the *Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars* (AM VI), a workshop that brought representatives from the lunar and the Mars communities together to identify overlapping capabilities and technical requirements.

NASA Progress and Status

NASA's Space Launch System (SLS) and Orion spacecraft are the backbone of the agency's plans to explore deep space. The first integrated launch of the system, which will be uncrewed and involve a journey around the Moon, is scheduled to occur in either late 2020 or 2021, with the first crewed mission following as early as 2022. As preparation for the first combined test of the Orion crew module and the SLS progressed in 2018, technical issues created schedule challenges that might jeopardize the 2020 launch date targeted for EM-1. As a result, NASA examined the possibility of using alternative launchers to test the Orion crew vehicle in a profile similar to a lunar mission. However, available alternatives would require multiple launches, as well as on-orbit rendezvous and docking operations to meet mission objectives. It was determined that the additional risk of these requirements would offset the potential advantage of using existing systems and would not provide schedule improvement over the SLS baseline. Therefore, NASA and its industry partners have committed to redouble their efforts to accelerate the schedule and increase confidence in achieving the EM-1 launch in 2020.

As NASA sets its sights on returning to the Moon—and preparing for Mars—the agency is developing new capabilities in lunar orbit to provide the foundation for human exploration deeper into the solar system. The Gateway is intended to provide a strategic presence in cislunar space, enabling activities with commercial and international partners that will ultimately translate toward human missions to Mars. The platform will consist at a minimum of a power and propulsion element (PPE) and a habitation element, with logistics and airlock capabilities. NASA plans to launch elements of the Gateway on the SLS and/or commercial rockets for assembly in space.

The power and propulsion element will be the first Gateway component, targeted to launch in 2022. Using advanced high-power solar-electric propulsion, this element will maintain the Gateway's position or move the Gateway among high lunar orbits. As part of the agency's public-private partnership work under Next Space Technologies for Exploration Partnerships, or NextSTEP, five companies have completed four-month studies on affordable ways to develop this element. Proposals were submitted and NASA intends to announce the selected PPE providers by the end of May 2019. Technologies developed for the power and propulsion element lay the groundwork for an eventual deep-space transport system for Mars.

Through Commercial Lunar Payload Services (CLPS) contracts awarded in late 2018, nine U.S. companies are now eligible to bid on tasks to deliver small science and technology payloads for NASA, including payload integration

Space Launch System. Image Credit NASA

and operations, launching from Earth, and landing on the surface of the Moon. NASA anticipates it will be one of many customers to use these commercial landing services. These commercial capabilities developed for lunar resupply and demonstrated through CLPS may very well be leveraged for eventual martian resupply.

NASA's second Next Space Technologies for Exploration Partnerships (NextSTEP-2) solicitation is a public-private partnership model seeking commercial development of capabilities to support human spaceflight missions. The solicitation focuses on developing deep-space habitation concepts, engineering design and development, and risk-reduction efforts. Under NextSTEP-2's Appendix A, five companies will deliver full-sized ground prototype habitats for testing in 2019. A sixth company is conducting a feasibility study and is under final negotiations to also deliver a ground prototype. Lessons learned from these ground tests will inform future lunar habitat—and eventually Mars habitat—development. Under Appendix E, issued in early 2019, NASA is also asking American companies to study the best approach to landing astronauts on the Moon. The agency's current reference design to send humans on roundtrip journeys to and from the surface of the Moon uses the Gateway and a system of three separate elements that will provide transfer, landing, and safe return. The new studies will refine this baseline approach. NASA anticipates two of the lander elements to be reusable, and the initial plan is for them to be refueled by cargo ships carrying fuel from Earth to the Gateway. The agency is also working on technologies to make rocket propellant using lunar water ice and regolith. Many of these technologies, systems, and operations developed for the Moon will serve to advance requirements, tailor applicable standards, and validate performance for similar systems needed for eventual human missions to Mars.

Under a variety of programs, including the NextSTEP teams and CLPS, NASA and their commercial and international partners are conducting capability maturation and system development in areas including precision landing; learning to use destination resources for fuel, water, oxygen, and construction; teleoperation of surface assets from orbit; science sample return; surface power generation and distribution; establishing deep space logistics supply chains; and development and testing of human-class ascent vehicles, pressurized surface mobility, and surface spacesuits.

Industry Updates

The following sections provide updates from several of NASA's commercial partners regarding their progress in 2018, as well as future plans.

Aerojet Rocketdyne

Over the past year Aerojet Rocketdyne has examined several new architecture variations that take advantage of the infrastructure developed for NASA's lunar Gateway. In general, they utilize the Gateway's capabilities as an aggregation and servicing facility at a point in cislunar space that makes it easy to reach and also easily used as a point of departure for missions. These concepts include lunar-surface exploration, as well as deep-space exploration to Mars and other destinations. The results show that the lunar Gateway does indeed provide benefits to a wide range of potential missions.

Lunar exploration missions, including those recently highlighted by the Vice President in his National Space Council speech, can take advantage of the Gateway to aggregate individual elements of the lunar landers, allowing them to be launched separately from Earth, thus broadening the opportunity to launch on a wide variety of commercial launch vehicles as well as the SLS. Over the past year, Aerojet Rocketdyne's concept-design work has focused on a capable and flexible Power and Propulsion Element (PPE) design that provides both Orion and a lunar lander element a stable base and servicing. Crew can rendezvous with the lander elements at the Gateway and transfer into the lander, while leaving Orion docked at the Gateway, where it can receive power and stationkeeping propulsion. This allows Orion to conserve its resources for operations in transit to and from Earth and also extends its ability to support longer duration missions on the lunar surface. Aerojet Rocketdyne continues work for NASA on the development of the Hall thruster propulsion system under the Advanced Electric Propulsion Systems (AEPS) contract. Figure AR-1 shows a collage of the Aerojet Rocketdyne vehicle design concepts including PPE for Gateway, an SEP cargo tug, and a notional NTP staged crew vehicle for Mars missions.

Figure AR. 1 Lunar Checkout and Infrastructure Enables a Variety of Exploration Missions to the Moon and Mars

In addition to the lunar Gateway studies, Aerojet Rocketdyne has collaborated with NASA, the Department of Energy's (DoE) Oak Ridge and Idaho National Lab), industry such as BWXT and USNC-Space to reduce the technical risk, refine the operability, and increase design fidelity for a Low Enriched Uranium (LEU) Nuclear Thermal Propulsion (NTP) system. Architecture studies have shown that the robust NTP Mars crew vehicle stage elements can be demonstrated at the Gateway in various configurations before flying the mission to Mars, further reducing risk to the crew. Using the Gateway requires that stage elements fit within the SLS 8.4-meter fairing, which in turn constrains the size of the LEU NTP.

Other architecture studies show the Gateway-based LEU NTP propulsive stage could be used as a "tug" for fast 48-hour cislunar crew or cargo transport or to send large orbiters to Jupiter, Uranus, or Neptune on higher energy trajectories that reduce transfer time by 30 to 50 percent. The LEU NTP architecture defined by the NASA, DoE, and industry team uses three 25,000 pound thrust engines at 875 seconds of specific impulse and carries all the propellant for performing the round-trip mission, which it can complete in 5 to 6 months each way. It will further reduce crew risk with its capability to abort during the early portions of the trajectory to Mars and arrive back home within months. The LEU NTP vehicle stage designs use hydrogen propellant storage technology under development at the NASA Glenn Research Center and Marshall Space Flight Center to maintain storage for the entire journey.

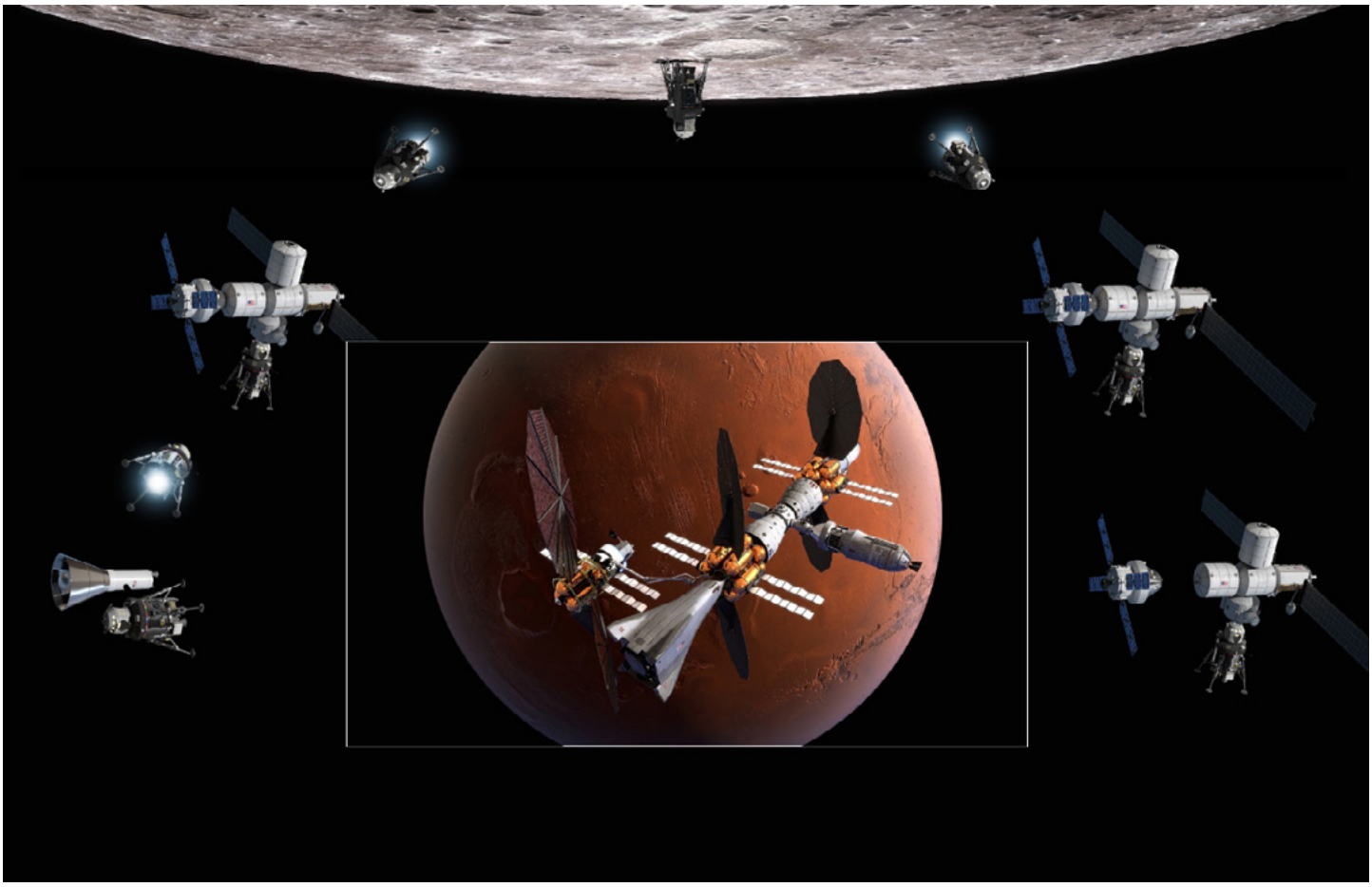


Figure LM-1 shows an overview of the Lockheed Martin architecture elements. Image Credit LMCO

Lockheed Martin

Mars Base Camp is Lockheed Martin's vision for sending humans to Mars. Operations from an orbital base camp will build on a strong foundation of today's technologies and emphasize scientific exploration as mission cornerstones. Key aspects of Mars Base Camp include utilizing liquid oxygen and hydrogen as the basis for a nascent water-based economy and the development of a reusable lander/ascent vehicle. Given the current directives to enable long-term deep space exploration, lunar exploration systems including landers should not be point solutions solely for the Moon. Just as the International Space Station is preparing us for long-duration human spaceflight, lunar activities can prepare us for Mars. The NASA Gateway is a key piece of infrastructure to enable lunar surface missions with reusable lunar landers, and it allows astronauts to demonstrate operations beyond Low Earth Orbit for months at a time. In 2018, Lockheed Martin released more details on the Mars Ascent/Descent Vehicle (MADV), a reusable, single-stage-to-orbit, mid-Lift/Drag vehicle with vertical takeoff and landing. Options for refueling the MADV between sorties were also outlined, including possible opportunities for commercial delivery of propellants to a fuel depot and/or *in-situ* production of propellants. Lockheed Martin also discussed a possible overall architecture for lunar exploration missions using precursor versions of the elements of the Mars Base Camp architecture.

The Boeing Company

Boeing has examined an architecture that leverages both the SLS transportation capabilities and the cislunar Gateway. The Boeing architecture uses a two-stage lander optimized to take advantage of the Gateway, including use of the Gateway to refuel the ascent module. As shown in Figure B-1, the four key elements can be deployed in a minimum number of launches using SLS, confirming the utility of the SLS for accomplishing early lunar missions. Other key aspects of the Boeing architecture are embodied in the feed-forward design that will enable the lunar lander design to be a pathfinder for a Mars lander design. Boeing's Mars lander concept uses the same structures, mechanisms, avionics, habitability systems, and EVA systems as the lunar lander and modifies only those subsystems required by the fundamental mission differences.

An overview of the Boeing architecture, with comparisons to Apollo and Constellation, is shown in Figure B-2.

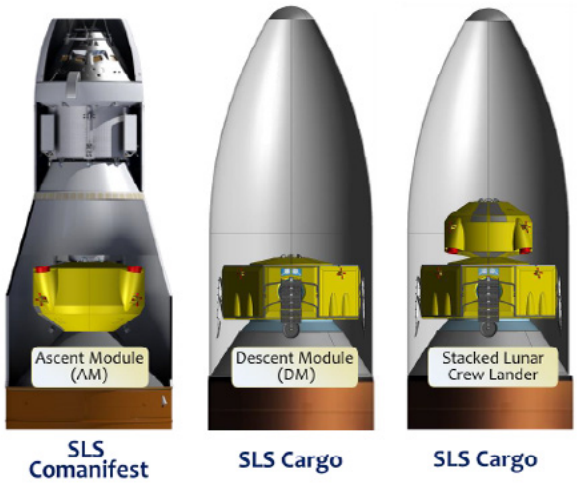


Figure B-1 Elements of Boeing Lunar Architecture Take Full Advantage of SLS TLI Mass and Volume Capabilities

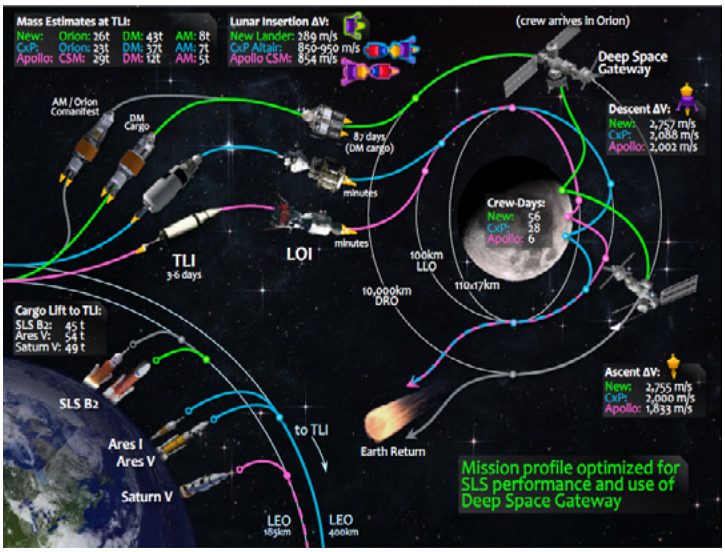


Figure B-2 Boeing Lunar Architecture with Comparisons to Apollo and Constellation Approaches B-2 Boeing Lunar Architecture with Comparisons to Apollo and Constellation Approaches

SpaceX Starship and Super Heavy Image Credit: SpaceX

SpaceX

SpaceX's Starship and Super Heavy rocket have been making rapid progress over the past year, including several flight versions of their methane-oxygen staged combustion Raptor engines entering testing and a flight-test vehicle

conducting its first hop in Boca Chica, Texas. SpaceX also announced an agreement with #dearMoon to fly a set of artists around the Moon on Starship by 2023, demonstrating the potential of their fully reusable launch and transportation system to open new human spaceflight markets.

Starship provides a very flexible set of capabilities, through its ability to deliver over 100 tonnes to LEO in a fully reusable fashion and, using propellant transfer, large quantities of cargo and eventually people to other destinations such as the surface of the Moon and the surface of Mars.

SpaceX is also conducting external workshops related to operations on the surface of Mars. These activities complement their internal efforts to provide a near-term, highly affordable transportation service to Mars. Overall, SpaceX remains on track to achieve their ambitious timelines to support human missions to the Moon and Mars in the 2020s

Sierra Nevada Corporation Gateway Concept. Image Credit: Sierra Nevada

Sierra Nevada Corporation

Sierra Nevada Corporation (SNC) has developed an architecture concept and full-scale ground prototype of two of the key elements of the lunar Gateway concept under NextSTEP-2 Appendix A Habitat Systems contract and NextSTEP-2 Appendix C Power and Propulsion Element Studies. SNC's Gateway is envisioned to provide critical technologies and capabilities for a human-tended, cislunar outpost for future lunar and deep space exploration. It can be assembled using SLS or commercial launch vehicles and features three unique platforms: the Power and Propulsion Element (PPE), the Large Inflatable Fabric Environment (LIFE) habitat, and the Extended Logistics and Control Module (ELCM). This architecture provides flexibility and is extensible to Mars. The modular nature of SNC's PPE design enables extension to provide solar electric propulsion for transportation services to Mars. The LIFE habitat was designed to support 1,000-day mission and has ample capability for both lunar and Mars missions.

The architecture leverages technology developed for the *DreamChaser™* Cargo System and is extensible to Low Earth Orbit (LEO), lunar surface and Mars. SNC has also been working with NASA on the future of LEO and recently completed a study for the commercialization of LEO. SNC's approach leverages significant previous industry and government investments to enable a vibrant LEO commercial economy. This flexible, modular architecture provides a cost-effective approach that fully supports current LEO activities, provides a graceful transition from ISS to commercial services, and gives enhanced capabilities that support the evolving future space commercial markets while ensuring a sustained human presence.

The Sixth Workshop on Affording, Achieving, and Sustaining Human Mars Exploration (AM VI)

In addition to the efforts by NASA and individual institutions described above, the series of AM workshops involved participants from multiple government organizations, academia, and industry. Approximately 70 subject matter experts on astronaut lunar and martian exploration, science, operations, and key technologies assembled in late August 2018 at The George Washington University to critically assess how operations, technologies, and facilities for the Moon and its vicinity might feed forward to astronaut missions to the martian surface before the end of the 2030s. This workshop was the sixth in the series of community workshops hosted since 2013 by Explore Mars, Inc., and the American Astronautical Society. Reports from previous workshops are posted at https://www.exploremars.org/affording-mars.

Using Mars exploration scenarios and enabling technologies from, respectively, the fifth (AM V) and fourth (AM IV) workshops, the workshop identified those lunar activities that show the greatest promise in enabling subsequent Mars exploration. Specifically:

Prioritized Space Transportation and Propulsion Systems, Technologies, and Operations

- **Long-term cryogenic fluid management:** Long-term storage of cryogenic propellants (LOX, LCH4, LH2), passive/active reduced boiloff tanking, liquid acquisition, tank mass gauging
- **Lander development** (e.g., propulsion, precision & autonomous landing, hazard avoidance): Cryogenic engines in the 40 - 100 kN range, deep-throttling engines, cryogenic reaction control system (RCS), precision landing, hazard avoidance
- **Vehicle aggregation** (e.g., refueling, refurbishing, checkout): Vehicle servicing, cryogenic refueling, refurbishment, repair, cleaning, re-certification for flight readiness
- **Human health and biomedicine** (e.g., radiation, psychosocial): Deep-space behavioral health monitoring, deep-space radiation

Surface Systems/Technologies/Operations

Highest priority (in alphabetical order):

- **Human health and biomedicine** (e.g., psychosocial, food & medicine)
- **Power systems** (e.g., fission for primary power, radioisotope power for mobility)
- **Rovers for human exploration** (e.g., operations, energy storage, airlocks, suitlocks)
- **Surface suits** (e.g., pressure garment, environmental protection layer, maintenance)

Next highest priority (in alphabetical order):

- **Communication systems** (e.g., orbital assets, local communication)
- **In-situ resource utilization**
- **Surface habitats and laboratories** (e.g., systems availability, operations)

The workshop produced a series of findings and observations, including:

- Early Mars missions do not necessarily require precursor lunar surface activities. However, the workshop identified various potential and important human and robotic operations, technology developments, and demonstrations on the surface of the Moon that would contribute in varying degrees to the Mars scenario adopted here (Field Station) during the 2030s.
- **A successful and sustainable Moon-to-Mars human space flight program requires a single "integrating" NASA Headquarters office** with budget authority to apply the results of technology, operations, and science trade studies [emphasis added]:
  - *Lunar and martian priorities should not be assessed independently of one another.*
  - *Future priorities for Mars exploration may levy requirements on lunar exploration.*

Team Photo of the AM VI Working Group

- The profound environmental differences between the Moon and Mars must be fully incorporated into scenarios that intend for the former to enable the latter.
- The Gateway may be an important testbed for Mars transportation architectures, if the final design includes that requirement.
- Using the International Space Station (ISS) or a LEO platform, where crews are continuously present using systems intended for Mars, is key for understanding how these systems will perform and potentially need to be maintained for a three-year Mars mission. In addition, permanent presence by crews in a zero-g and relatively isolated and stressful environment is critical for reducing human health and biomedicine risks for long-duration missions.
- Two martian engineering or technology "long poles"—crew and cargo landers and martian system reconnaissance—have very long development times. If development of these "long poles" is delayed, the accomplishment of landing humans on the surface of Mars will likewise be delayed.
- The workshop found significant value in the Moon and Mars communities working together to understand how lunar operations and capabilities can feed forward to Mars. They recommend a more extensive assessment with increased joint participation by these communities.

Finally, the AM VI workshop recommended that several important studies be undertaken, one by the National Academies, as well as a series of trade studies that could be carried out by a broad community of subject matter experts. The proposed National Academies study would evaluate in-situ resource utilization (ISRU), especially of surface/shallow geological deposits containing extractable water, as to the potential to enable affordable and sustained human occupation of both the Moon and Mars. At present, certain critical information about these resources is not yet available and, consequently, how and when such resources might be exploited is unclear, specifically:

- *What are the priority surface and orbital reconnaissance programs of potential lunar and martian resources to assess their potential?*
- *What is the degree to which lunar resource exploration, production, beneficiation, and commodity storage processes enable and feed forward to Mars?*
- *What are the anticipated effects of declining launch costs and development of lunar resource extraction capabilities?*

The proposed series of additional trade studies are (not in priority order):

- Comparison of end-to-end costs of resources extracted from the Moon with those supplied from terrestrial sources
- Lunar ascent vehicle/lander extensibility to Mars ascent vehicle/lander
- Pros/cons of different cryogenic propellant combinations (i.e., LOX/CH4 versus LOX/H2) for lunar and Mars scenarios
- Value of remotely operated robots versus on-site astronaut operations on the lunar surface to feed forward to human missions to Mars
- Airlock versus suitlock, including planetary protection, habitat access, and cognizance of different environment
- Common development paths for Mars and Moon surface suit thermal systems
- Long-lived pressurized rover energy production and storage [e.g., Kilopower versus radioisotope power system (RPS), fuel cells versus batteries]
- Rover needs on the two worlds [e.g., duration of trips, what rovers are used for (science, construction, maintenance, transportation), day-night cycle, and crew size]
- Study of ISRU-based site preparation and construction for landing, lift-off, and surface transportation operations on lunar and martian terrains

HUMAN HEALTH AND PERFORMANCE

Human System Risk for a Mission to Mars

Journeys to Mars will be the next great endeavor in human exploration. Similar to prior feats of exploration, keeping the people making the journey healthy and productive is a challenge unto itself. There are both known and unknown risks in current architectures for human missions to Mars that will need to be planned for and countered.

Maintenance of Health

The extended duration, isolation, and novel operational environment of a Mars mission necessitates more robust health monitoring, maintenance regimen, and autonomous intervention protocols than any previous human spaceflight mission in order to maintain crew heath and performance. In comparison to the Low Earth Orbit operations of the International Space Station (ISS) and all prior human spaceflight, a mission to Mars has restricted re-supply capability, delayed ground-support communication, and no ability to abort to a higher level of medical care during most phases of the mission.

On the ISS, crewmembers have 24/7 ground support with near instant communication to physicians, specialists, and biomedical engineers to address medical issues and to troubleshoot equipment malfunctions. Mars missions will have significant delays of up to 40 minutes in communication, reducing the amount of real-time guidance for procedures or diagnostics. Although improvements to existing communications infrastructure at Mars are expected, the delay in communications will still impact our ability to detect subtle changes in health that could predict mission-impacting issues before they occur. The communication delay necessitates more emphasis on intelligent systems that can provide decision support and monitoring to assist crewmembers assigned to medical operations. Along the same lines, significant autonomy and robust operations will need to be incorporated into the medical system design as evacuation to a higher level of care will be a functional impossibility during most phases of a Mars mission. In addition, mission operations will need to be prepared to face medical event outcomes that might have a higher morbidity and mortality than is expected on Earth due to the duration and resource limitations of Mars missions. The duration alone (1,100 days) will limit the efficacy of pre-screening the longer the astronauts are away. These realities may require a fundamental culture shift in mission operations and an increased reliance on intelligent systems to ensure crew health.

Current work in this area is focused on designing on-board medical support software to function as an assistant to the crew medical officer without direct ground control and operation. NASA and the clinical medicine community are focused on developing and updating risk models with clinical data over time to better predict real-time health status, changes, and in-flight medical event risks. These models will help identify which specific health conditions will have the largest mission impact through either acuity or likelihood. From there separate research efforts can start or be refocused on countermeasures for the highest priority conditions. These countermeasure efforts can then be fed back into the prediction model for a feedback model to monitor how overall risk of medical issues is impacting the mission risk models as a whole.

Exercise is a known countermeasure that improves and maintains crew health and performance, but the existing hardware on ISS is likely too large, maintenance heavy, and resource intensive for an exploration mission to Mars. Smaller, more efficient devices will need to be developed and deployed with meaningful run-times to validate their efficacy. Alternatively, medication assisted muscle and bone maintenance regimens, that reduce the amount of exercise required to maintain muscle and bone function, may be developed. Currently crewmembers must exercise 2-3 hours/day, which is a significant driver of daily schedules. Whichever option mission planners pursue, recovering from the 9 months in 0-G transit from Earth to Mars is expected to require significant exertion and strength from deconditioned crewmembers. As such, maintaining crewmember's strength and function is not only for crewmember comfort but may be the difference between survival and death for the first crew to arrive on Mars.

To better understand how crew members will perform during the initial days of mission-critical tasks on the surface of Mars, there are plans underway to simulate this scenario. In a special study commissioned by the NASA ISS Program and presented at the *ISS4Mars: ISS and Mars Mission Analog Workshop* that took place in Rome, Italy in October 2018, scenarios were outlined that would model both Mars transit and the first days of a Mars landing using ISS crew. After a stay at ISS, crew members would occupy a mobile facility that can simulate a pre-positioned habitat for a period of between 1 and 3 days. During the stay on ISS, crew may also be subjected to simulated technical problems or medical emergencies.

Immune system dysregulation is another known risk of long duration spaceflight that is an active area of research for the space life science community. Recent work has confirmed that the human immune system is less effective during spaceflight and that pathogens that can affect humans are more virulent. The causes of these phenomena are still unknown but many of the countermeasures used to address other human health issues are also effective in improving immune health. Additionally, the burgeoning field of precision medicine may inform targeted pharmacologic interventions that are crewmember specific and can be identified prior to flight.

With extended duration crew rotations greater than one year, the ISS is an ideal test-bed for these technologies. Isolation and communications delay can be simulated in a very similar analog environment with a higher margin of safety in terms of evacuation potential.

It is also worth noting, however, that we do not yet fully understand all of the hazards that exist on the Martian surface. There may be health risks associated with the Martian regolith/dust due to its toxicity, potential for respiratory harm, or biological risk from extant Martian life, if it exists. These risks may not impact the success of the mission, but further study will be required to rule them out. Mars sample return missions and missions to access Martian subsurface ice may prove vital to answering open questions in this area.

Fig 1. Astronaut Serena Auñón-Chancellor examines her eye with a Fundoscope aboard the International Space Station with remote support from doctors on the ground. Image Credit: NASA

Fig 2. Astronaut Alexander Gerst practices CPR as cosmonaut Sergey Prokopev looks on during an emergency training session aboard the International Space Station. The onboard training provides crewmembers the opportunity to review safety procedures, communication methods and hardware necessary to manage a medical emergency. Image Credit: NASA

Fig 3. JAXA astronaut Norishige Kanai is photographed removing the Plant Habitat growth chamber door and the science carrier. Dwarf wheat plants are visible. Plant Habitat is a fully automated facility that is used to conduct plant bioscience research on the International Space Station. Image Credit NASA

Consumables

It is a staple of medical dogma that good diet leads to better health outcomes, both in physiology and behavioral health contexts. On the ISS, food and medications are re-supplied at every opportunity, yet still one of the most common crewmember complaints is the taste or quantity of the preferred food available to them. On a Mars mission the food available at the outset is the amount available for the entire trip, absent food grown during transit or obtained from pre-placed, in-space depots (though these supplies will be older than the food brought with the crew). Food and other perishable goods are exposed to the same gravitational and radiation environment as the rest of the spacecraft, impacting their flavor, stability, nutritional content, and potency. Ideally, crews could use the significant transit time during a Mars mission to grow and harvest a fresh, flavorful, and

sustainable food source to be used during the mission. This is an active area of ISS research and also could provide further benefits of supplemental carbon dioxide scrubbing, removal of nitrates from water supply, plants with pharmacologic applications, radiation shielding from the soil/water stores, and potentially behavioral health improvements from the presence of greenery (hypothesized to provide psychological benefit, but currently not a validated countermeasure).

Providing effective medications presents its own challenges. For instance, identifying a medical condition early is not sufficient if the medications required to treat that condition have degraded due to the spaceflight environments, so efforts are needed to monitor pharmaceuticals for efficacy during the flight and to design the storage environment to reduce radiation and exposure degradation. It is not currently known whether the existing food and medication storage procedures for ISS will suffice for a Mars mission, as most methods only certify stability for around 2 years whereas a Mars mission is projected to take around 3 years. Also, many storage options available for extending the duration of consumables require significant refrigeration systems that challenge mass, volume, and power constraints for an extended duration mission. Development of appropriate storage technology and maintenance protocols will require extended duration ground and ISS analogs for Mars missions to longitudinally test performance and efficacy.

Deciding which and how much of various medications the crew will bring will guide storage and maintenance decisions. Using models of human health and performance, the goal should be to determine the fewest amounts and types of medication that will treat the broadest indications and medical conditions that are likely to develop in-flight during a Mars mission.

Behavioral Health and Cognitive Function

Humans can be greater than the sum of their parts when working in a team; however the makeup and size of the team and the context of the team's operation are essential elements in optimal performance. A Mars mission will be long (most assumptions are of >1000 days of mission time), isolated, cramped, and cover wildly different environments (e.g. deep space, Mars orbit, Mars surface) across the mission phases. Each of these factors can negatively affect teamwork and performance. Also, potential radiation effects on cognitive function could exacerbate these dynamics.

Currently, space agencies do most of the work of behavioral health and cognitive function assessment during the selection phase of astronaut training. During ISS increments crewmembers are given almost free-range to communicate with their families and the Earth through telephone calls, emails, and social media, which may be available during a Mars mission but in a significantly delayed and limited capacity. Furthermore, due to the extended duration and isolation, Mars missions will have many more stressors with fewer opportunities for mitigation compared to ISS, presumably leading to higher incidences of behavioral or psychiatric issues. Current management strategies include verbal behavioral health counseling with the ground and potential pharmaceutical intervention. Real-time counseling will be limited and likely frustrating with communication delays inherent in a Mars mission and resource constraints will limit the ability to utilize medications, both of which could further stress an already stressful environment.

Of the many unknown effects of radiation, damage to the neurologic system due to continued exposure to the interplanetary radiation environment is a potent unknown. Any decrease in cognitive function is known to increase aggression and decrease interpersonal skills, a potentially toxic combination in an environment dependent on cohesive team dynamics.

Countermeasure development in this area is focused on monitoring of behavioral health, assessments of cognitive function, investigation of relevant biomarkers, and efforts to characterize the effect of radiation exposure on neurologic processes to further inform medical interventions that may alleviate these effects. At this point in time, most radiologic testing is being done in tissue and rodent models, while other behavioral health research and interventions are being studied in analog environments such as Antarctica and the Human Exploration Research Analog (HERA) system at NASA.

There are several interventions that are currently being developed from ongoing research, including better defined selection criteria based on ideal team dynamics, monitoring and trending radiation-associated biomarkers for pharmaceutical targeting, virtual reality assisted behavioral health counseling for real-time interventions with interpersonal conflict, and modification of exercise regiments to optimize their positive psychologic effects.

Integrating Humans into the Overall System

Utilizing all of the above research and development will require a change in the way humans are integrated into the overall flight system from the way NASA and other space agencies have operated in the past. Crew will have to be integrated into the vehicle as design elements rather than treating them as crewmembers who will be trained to perform specific tasks. It will likely be impossible to train crew to the depth of knowledge currently required for every mission-critical task known or likely to occur during a Mars mission, or for mission-critical tasks that are not likely to occur, but if they do nevertheless occur would cause mission failure if not addressed properly. This is due not only to the duration of the mission, but also to the sheer number of events that might occur during a multi-phase 3 year plus duration mission, as well as the retention of skills required for rare events. This gap in current procedure and required training regimens drives requirements both for new approaches in training as well as integrating information and crew training to a system that is designed with the vehicles from their earliest inception. Training crewmembers in concepts rather than rote procedures, and treating crewmembers as a component of mission design rather than operators of mission procedures, are promising approaches. Further research and development in just-in-time training including virtual and augmented reality assisted training, decision support systems, systems designed for in-flight maintenance and modification, human-robot interaction, and crew resource management are all part of managing these risks as well.

Integrating the crewmembers into the wider flight system will involve planning for the ergonomic differences due to the increased diversity and gender differences in current and future crew populations. As seen with the aborted plan to undertake the first all-female spacewalk at ISS in 2019, the majority of the systems and equipment in previous systems were inventoried and designed with male astronauts as the baseline design type. It should be assumed that female astronauts will likely comprise at least half of the crew population intended for Mars and exploration flight and as such we should assure that systems and equipment are designed in a manner to accommodate a wider range of body shapes and physiologies.

NASA is aware of these integration challenges and, as an engineering-focused agency that has had difficulties in the past in appropriately integrating the contributions of physicians and life-scientists, published a lessons learned technical report entitled, “Engineering, Life Sciences, and Health/Medicine Synergy in Aerospace Human Systems Integration: The Rosetta Stone Project” (NASA SP-2017-633). This report, commissioned by NASA’s Chief Engineer and Chief Health and Medical Officer, details the results of the failures and successes of this integration over NASA’s history and proposes methods and ideas to prevent future failures and build on the successes to improve the chances of getting Humans to Mars.

Recommendations:

- Better defined exploration goals and timelines than currently provided by the Administration and Congress should guide research and development outcomes for Human Health and Performance system design.
- Multiple additional year-long missions with diverse populations in Low Earth Orbit that evolve to the duration of human Mars missions will be required. We might also consider sending astronauts from the ISS to Mars analogs to investigate how self-guided recovery impacts both health and productivity with realistic communications delay.
- Missions beyond Low Earth Orbit will be required to study issues specific to long distance spaceflight that can only be effectively addressed farther away from Earth.
- Stable, adequate funding, and prioritization of human health in space research initiatives, are required, with increased partnerships and collaboration amongst governmental agencies, commercial providers, physicians, researchers, spaceflight participants, etc.
- Design and integration of the human system to account for the wider ergonomic and physiologic diversity of crew gender and body types.
- Expand plans to conduct Mars mission simulations utilizing both the ISS and ground stations. After initial analog missions mentioned earlier in this section, missions of greater length and complexity should be conducted.

POLICY: OPPORTUNITY and CHALLENGES
Achieving the Moon and Mars

As plans advance for an accelerated return to the Moon, the goal of landing humans on the surface of Mars in 2033 also came into more focus over the past year. Developing a program that is sustainable – both financially and politically – is also being embraced by policymakers. Indeed, thanks to efforts such as the *Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars* (AM VI), held in August 2018, an important dialogue has begun involving the lunar and Mars communities to critically assess how operations, technologies, and facilities for the Moon and its vicinity might feed forward to astronaut missions to the martian surface. (https://www.exploremars.org/wp-content/uploads/2019/01/AM-VI_FinalReport_DigitalOnly_012919.pdf) These steps are essential to create sustainability and assure that Mars remains the target destination in the 2030s.

However, these goals will also require that sufficient funding and political support are provided. Otherwise, the program could turn into a 'Moon-only' program – or might not even be able to achieve that intermediate goal.

While the recent report of the *Science & Technology Policy Institute* cast doubt on missions to Mars in 2033, it remains likely that human missions to Mars in 2033 are feasible with the proper commitment of funding, political approach, and smart mission planning recommended in this report.

It has been a busy year in policy circles:

1. **Confirmation of the NASA Administrator and Deputy Administrator:** NASA leadership went through a transformation when Jim Bridenstine was confirmed as NASA Administrator in April 2018 and Jim Morhard was confirmed as Deputy Administrator in June 2018.

2. **Statements from the Administration:** The President and Vice President continued to issue positive statements regarding sending humans into deep space, such as:

- ★ ***President Donald Trump***

  In a statement to the National Space Council in June 2018, President Trump said, "(We will) …return Americans to the Moon for the first time since 1972…This time… we will do more than plant our flag and leave our footprints. We will establish a long-term presence, expand our economy, and build the foundation for the eventual mission to Mars."

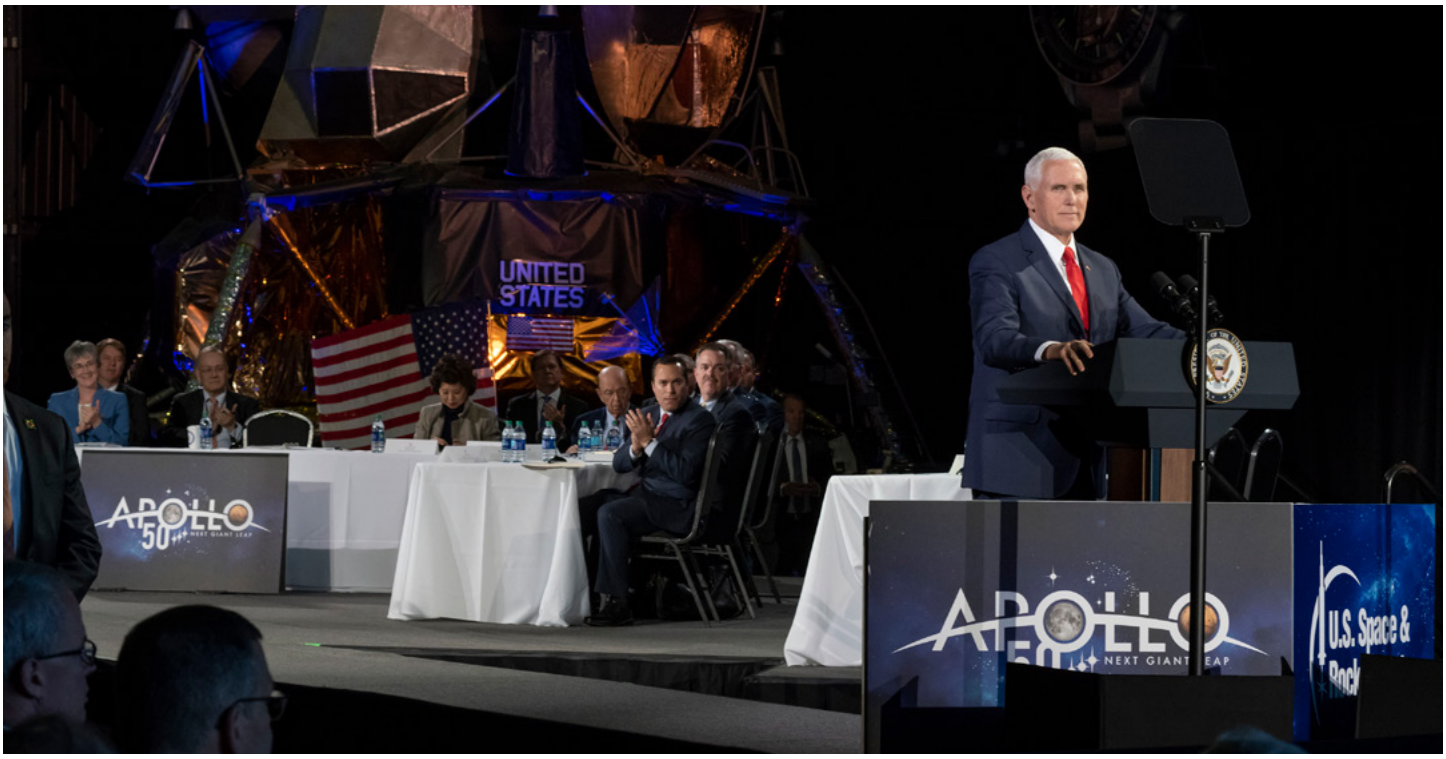
- ★ ***Vice President Mike Pence***

  At the National Space Symposium held in Colorado Springs in April 2018, Vice President Pence referenced the goals of landing humans on Mars while discussing the Gateway. "From this orbiting platform, and with our international and commercial partners, American astronauts will return to the moon to explore its surface and learn how to harness its resources to launch expeditions to Mars."

  During a speech at NASA's Johnson Space Center in August 2018, Vice President Pence stated, "We're … renewing our commitment to discovery and exploration, and to write the next chapter of our nation's journey into space…It is now the official policy of the United States of America that we will return to the moon, put Americans on Mars and once again explore the farthest depths of outer space."

3. **Return to the Moon in 2024. Humans to Mars in 2033**

During the 5th National Space Council meeting that took place on March 26, 2019 in Huntsville, Alabama, Vice President Mike Pence announced that it is now the stated policy "of the United States to return humans to the surface of the Moon" by the year 2024. In addition, NASA Administrator Jim Bridenstine announced at this meeting that NASA will create a new "Moon to Mars Mission Directorate" that will coordinate plans to return humans to the Moon and then to send them on to Mars. In order to accomplish this goal in this accelerated timeframe, however, the necessary funding and political support must be generated.



Vice President Mike Pence, chairman of the council, presiding over the 5th meeting of the National Space Council. Image Credit: NASA

At a hearing of the House Science, Space and Technology Committee on April 2, 2019, NASA Administrator Bridenstine reemphasized NASA's Mars timeline stating, "We want to achieve a Mars landing in 2033…In order to do that, we have to accelerate other parts of the program, and the moon is a big piece of that."

However, shortly after these objectives were outlined, the Science & Technology Policy Institute released a report called "Evaluation of a Human Mission to Mars by 2033." This report cast doubt on the feasibility of humans missions to Mars in 2033 stating that, "a Mars 2033 orbital mission cannot be realistically scheduled under NASA's current and notional plans. *Our analysis suggests that a Mars orbital mission could be carried out no earlier than the 2037 orbital window without accepting large technology development, schedule delay, cost overrun, and budget shortfall risks.* Further budget shortfalls or delays in the construction or testing of the DST would likely require the mission to depart for Mars in 2039 at the earliest." As such, the Administration, NASA, and its partners will need to clearly articulate how their new timeline for returning humanity to the Moon can also lay the groundwork for Mars missions in 2033.

4. **Policy Directives**

The Administration released two additional space policy directives in 2018 and one additional one in early 2019. While none were specifically related to human missions to Mars, two nevertheless take important steps that will enable safe commercial and government expansion into space, while the other deals with military space.

5. **President's Budget Proposal**

In mid-March 2019, the Trump Administration released its proposed FY2020 budget. It called for a $21.019 billion budget for NASA. In contrast, NASA's actual FY 2019 enacted budget was approximately $21.5 billion. The budget proposal seeks to support efforts to return to the Moon, including allotting funds to purchase commercials flights to the Moon. It also fully funds the Mars 2020 mission, and provides initial funding support for a Mars sample-return mission that could launch as soon as 2026. However, among other things the budget proposes to cancel the Wide-Field Infrared Survey Telescope (WFIRST) and eliminate funding for the Office of Science, Technology, Engineering, and Mathematics Engagement (formerly known as the Education Office). Also subject to a decrease in funding is the crewed space exploration program (SLS and Orion).

However, a revised proposed NASA budget was expected to be released in late April/early May 2019, which would presumably address the needs of the accelerated timeline. However, at the time that this publication went to print in late April, such a revised budget had not yet been released.

6. **NASA Report to Congress**

National Space Exploration Campaign Report – In September 2018, NASA delivered the *National Space Exploration Campaign Report* as required by the *NASA Transition Authorization Act of 2017*. According to this document, "The National Space Exploration Campaign aims to revitalize and add direction to NASA's enduring purpose to carry out human and robotic exploration missions, expanding the frontiers of human experience and scientific discovery of the natural phenomena of Earth, other worlds, and the cosmos as a whole."

The report provides five strategic goals for NASA:

1. Transition U.S. human spaceflight in LEO to commercial operations that support NASA and the needs of an emerging commercial economy.
2. Lead the emplacement of capabilities that support lunar surface operations and facilitate missions beyond cislunar space.
3. Foster scientific discovery and characterization of lunar resources through a series of robotic missions.
4. Return U.S. astronauts to the surface of the Moon for a sustained campaign of exploration and utilization.
5. Demonstrate on the Moon the capabilities required for human missions to Mars and other destinations. https://www.nasa.gov/sites/default/files/atoms/files/nationalspaceexplorationcampaign.pdf

7. **Congressional Hearings:** Both houses of Congress continued to conduct hearings dealing with the overall goals and execution of our space program. Two hearings in particular were specifically relevant to the goal of landing humans on Mars:

- On July 25, 2018, the Senate's Space, Science, and Competitiveness Subcommittee conducted a hearing entitled, "Destination Mars: Putting American Boots on the Surface of Mars." Witnesses were Tory Bruno, President and CEO, United Launch Alliance; Peggy Whitson, former NASA astronaut; Dava Newman, MIT professor and former NASA Deputy Administrator; and Chris Carberry, CEO, Explore Mars, Inc.

  During this hearing, Sen. Ted Cruz (R-Texas) stated that, "While the Moon will provide a great testing ground in preparation for the journey to Mars, we must remain vigilant and ensure that we limit costly delays that could push a crewed Mars mission in the 2030s out of reach…Mars is today the focal point of our national space program." In addition, the ranking member of this subcommittee, Sen. Ed Markey (D-Mass.), stated, "We need to help NASA lift its gaze past the moon and understand how the work we do in space closer to Earth will serve us in our quest for Mars."

Explore Mars, Inc. CEO Chris Carberry, MIT Professor Dava Newman at Senate Hearing 2018. Image Credit Explore Mars, Inc.

- On September 26, 2018, the U.S. House of Representative's Space Subcommittee held a hearing entitled, "60 Years of NASA Leadership in Human Space Exploration: Past, Present, and Future". Witnesses were William Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA; Mark Geyer, Director, Johnson Space Center, NASA; Jody Singer, Director, Marshall Space Flight Center, NASA; and Robert Cabana, Director, John F. Kennedy Space Center, NASA.

  In his written testimony, William Gerstenmaier, NASA Associate Administrator for Human Exploration and Operations, stated that "NASA will advance robotic access to Mars in preparation for human exploration".

- On March 13, 2019, the House Committee on Science, Space, and Technology conducted a hearing entitled, "America in Space: Future Visions, Current Issues". This hearing focused on pressing challenges to our nation's space program, including proposed cuts to NASA's education budge, orbital debris, anti-satellite threats, the rise of competing powers, and other related issues. Witnesses were: Dr. Ellen Stofan, John and Adrienne Mars Director, Smithsonian National Air and Space Museum, Former NASA Chief Scientist; Dr. Peggy Whitson, Technical Consultant and Former NASA astronaut; and Mr. Frank Rose, Senior Fellow, Security and Strategy, The Brookings Institute, Former Assistant Secretary of State.

During this hearing, Chairwoman Eddie Bernice Johnson (D-TX-30th) stated, "If we want America to lead with a visionary and effective space program, we must be willing to commit the resources and funding stability to achieve it."

- On March 13, 2019, the Senate's Commerce, Science, and Transportation Committee conducted a hearing entitled, "The New Space Race: Ensuring U.S. Global Leadership on the Final Frontier". This hearing discussed the U.S. government's strategy for maintaining leadership in space, ensuring space industry competitiveness, and addressing challenges to spacefaring preeminence. Witnesses were: The Honorable Jim Bridenstine, Administrator, NASA; and Mr. Kevin O'Connor, Director, Office of Space Commerce, Department of Commerce.

  During this hearing, NASA Administrator Bridenstine indicated that the agency was considering an option to utilize commercial launch vehicles, instead of the Space Launch System (SLS), to launch the uncrewed test flight of Orion around the Moon, known as Exploration Mission 1 (EM-1).

- On April 2, 2019, NASA Administrator Jim Bridenstine testified at a hearing conducted by the House Science, Space and Technology Committee reviewing NASA's FY 2020 budget request. During this hearing, Bridenstine emphasized that landing humans on the Moon in 2024 will enable sending humans to Mars in 2033.

8. **Legislative Outreach**

Numerous space advocacy groups continued their calls for a strong and sustained commitment by the United States to deep space exploration, including for human missions to Mars by the 2030s. Several grassroots visits to Capitol Hill were organized and conducted by various organizations in early 2019, including the annual "Legislative Blitz" held by the Space Exploration Alliance (SEA), a collaboration of non-profit space advocacy organizations. In such events, people from around the country come to Washington, DC to convey to our elected representatives the importance that the general public attaches to NASA and our nation's space exploration efforts, and to call for adequate and sustained funding for our civil space program so that NASA can accomplish all that it has been tasked with by the legislative and executive branches. For example, in the 2019 Legislative Blitz, participants called for, among other things, a 5% increase, per year, for the next 5 years, in NASA's budget.

9. **Exploration Policy Findings**

Our review of the current status of policy guidance for Space Exploration led to a consensus on some areas where it was believed providing specific findings to policy makers in the Congress and the Administration might be helpful:

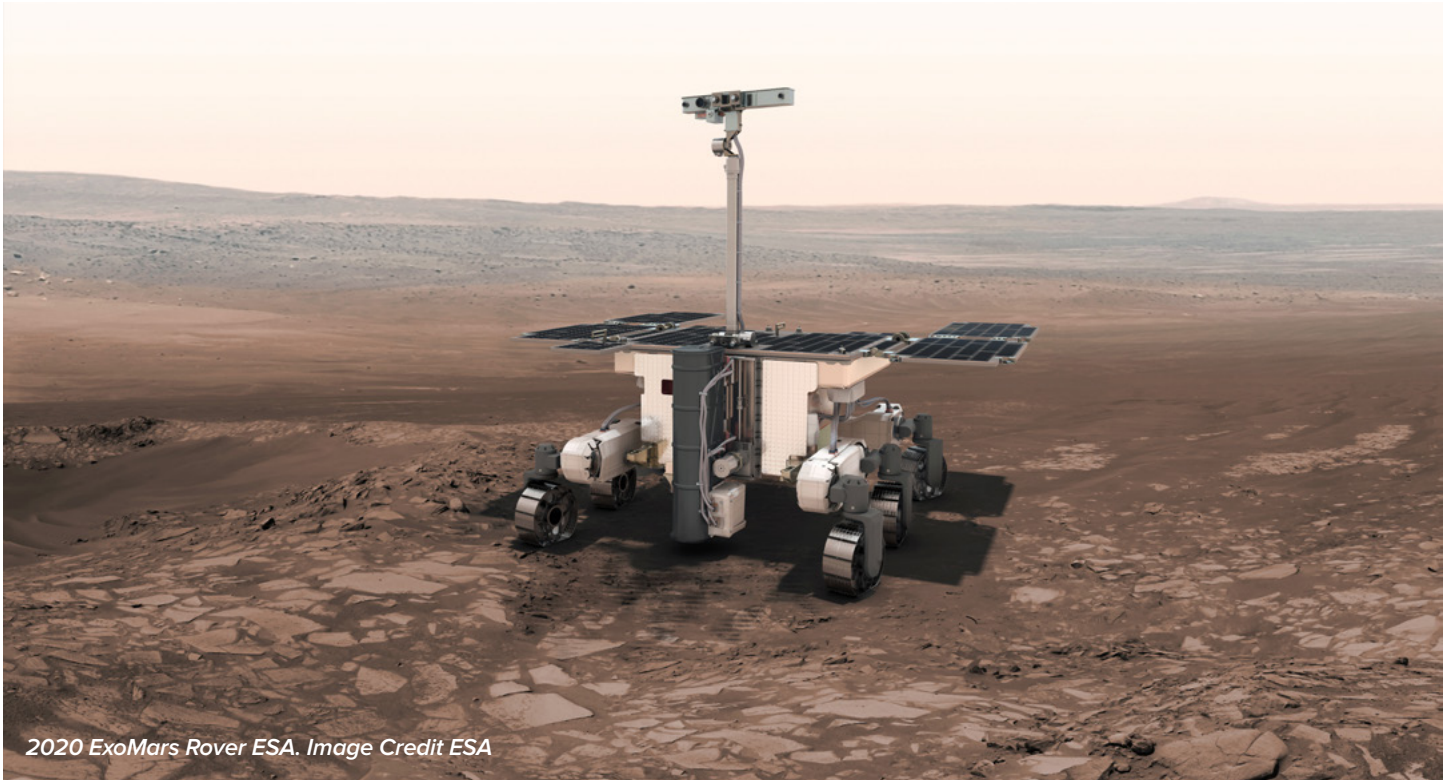
- As lunar activities are developed, such plans should be constructed in a manner that should feed forward to and therefore advance the goal of human missions to Mars in the 2030s and should not hinder achieving that goal.

- NASA and its international and industrial partners should advance the development of systems, technologies, and operations that show promise in enabling human missions to both the Moon and Mars, as indicated in the *Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars* (AM VI), https://www.exploremars.org/wp-content/uploads/2019/01/AM-VI_FinalReport_DigitalOnly_012919.pdf)

- Continue to foster synergies and collaboration between government and private entities to create policies and programs that effectively utilize the Moon on the path to Mars.

- None of the ambitious goals noted earlier can be achieved without clear plans going forward, sufficient funds to accelerate these programs, and strong and sustainable political support. Without all three of these elements, these goals are unlikely to be realized.

International Policy



2020 ExoMars Rover ESA. Image Credit ESA

An achievable and sustainable program of robotic and human exploration of the Martian surface will require a multi-national effort. While there is no unified international consensus on a timeline for sending humans to Mars, there is growing interest in the international community in the exploration of Mars.

Several countries and space agencies have impressive programs underway that could have a substantial impact on the goal of sending humans to Mars.

Some of the current missions or programs include:

1. Europe

As noted in the science section, Europe has several active programs that are highly relevant to Mars exploration. The ExoMars program consists of two missions: One is the Trace Gas Orbiter, which included an Entry, Descent and landing demonstrator Module (EDM) known as Schiaparelli, launched on March 14, 2016 and arrived at Mars on October 19, 2016; and the other mission features a rover with a scheduled launch date in 2020. The ExoMars Trace Gas Orbiter is at present mapping the water in the upper crust of Mars and providing more refined details of localized 'wet' and 'dry' regions. Both missions are carried out in cooperation between the European Space Agency (ESA) and Roscosmos (the Russian Space Agency). The main objective of ExoMars is the search for evidence of life on Mars.

European interest also continues to grow for conducting a Mars Sample Return mission. As an example, a Mars sample return mission was the focus of the *2nd International Mars Sample Return Conference*, which was held in Berlin, Germany from April 25-27, 2018. This conference was co-hosted by ESA and France's National Centre for Space Studies (CNES), in cooperation with NASA and the International Mars Exploration Working Group (IMEWG). In addition, Mars 2020, a robotic mission planned by NASA in conjunction with international partners, has as part of its current mission the objective to profile the collection and preservation of soil samples from Mars for retrieval during a later sample return mission.

Gateway: There has been steadily growing interest among ESA and members of the European space community to support the Deep Space Gateway. This could serve as a catalyst to expand the International Space Station (ISS) partnership to activities beyond low Earth orbit.

AMADEE: In February 2018, the Austrian Space Forum in partnership with the Sultanate of Oman conducted AMADEE-18, a Mars analog field simulation in the Dhofar desert region of Oman. Following up on this program, the Austrian Space Forum has announced AMADEE-20 that will be conducted in cooperation with the Israel Space Agency in the Negev Desert, Israel.

2. Asia

The United Arab Emirates (UAE) is particularly committed to Mars exploration. The Emirates Mars Mission a/k/a *Hope Mars Mission*, with its unmanned Hope orbiter that will study the Martian atmosphere and climate, is scheduled to arrive at Mars in 2021 to coincide with the 50th anniversary of the founding of the UAE. In addition, the UAE's Mars Science City, currently in the design phase, will be built near Dubai. Scheduled to be completed by 2023, this simulated, prototype Mars city/analog will stimulate international collaboration to advance Mars exploration and will inspire STEM education throughout the Middle East and around the world. The UAE also has some extremely ambitious long-term goals.

The Indian Space Research Organization (ISRO) is planning a follow-up mission to its successful Mars Orbiter Mission (MOM) spacecraft of 2016. Scheduled to launch in 2021, MOM-2 (also called Mangalyaan 2) may also include India's first Mars lander.

The Japanese "Martian Moons eXploration" (MMX) mission is designed to clarify the origin of the Martian moons and the process of evolution for the Mars region. It is scheduled to launch in the early 2020s and will be the first sample return mission from the Martian system as well as the first round trip demonstrator.

China also plans to send an orbiter, lander, and rover to Mars, with a target launch date of 2020. Furthermore, China has recently revealed its desire to ultimately establish human settlements on Mars.

3. Australia

In July 2018, the government of Australia officially launched the Australian Space Agency. This organization is intended to grow the Australian space industry; create better collaborations between government, industry, and academia; and strengthen international collaboration. Australia already plays a critical role in the success of Mars missions with the Canberra Deep Space Communication Complex.

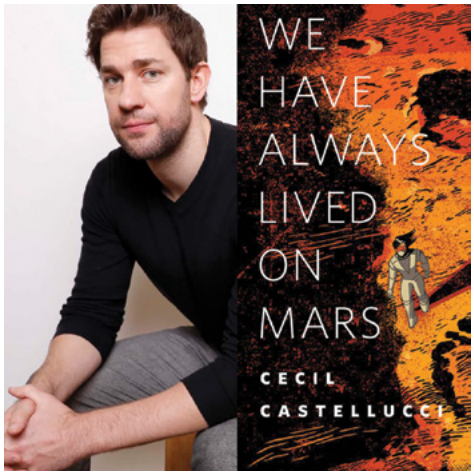
Findings for enhancement of international collaboration and participation surfaced in the examination of current international activities. These recommendations are offered for consideration as Exploration Program architectures become more refined and their implementation proceeds:

- Based on the success of The Sixth Community Workshop for Achievability and Sustainability of Human Exploration of Mars, similar workshops and programs should be conducted around the world not only to identify overlapping requirements/capabilities for sending humans to both the Moon and Mars, but also how to build an effective international coalition to achieve these goals attainably and sustainably.
- While most of these missions/programs promote international collaboration, there is a need for far greater coordination of efforts in order to truly advance international science and human missions to Mars. This coordination among the respective agencies, organizations, and/or partnerships could start with data sharing agreements in such a manner that science/robotic missions to Mars can build on one another to maximize readiness for future human missions.
- As long as valid security concerns by the United States and its international partners are sufficiently addressed, the role of China in future international efforts to reach Mars should be considered by Congressional and Administration policy makers.
- International Space Station (ISS): The ISS is being used today to test equipment, to develop operations concepts, and to better understand the physiological and psychological impacts of being in space for extended durations. It is also an important model of a successful international partnership in space exploration, as well as a model of a sustainable program. This partnership should be extended by the current ISS partners as well as new partners to form an international cooperative effort aimed at moving humanity beyond low Earth orbit and on to Mars.

THE PERCEPTION ELEMENT

How Public Interest Impacts & Drives Mars Exploration

Mars Season 2 aired November to December 2018. Image Credit: National Geographic



Life On Mars: In preproduction with John Krasinski (above) slated to direct. Image Credit: Matt Sayles AP, Book Cover Art: Carl Wiens

The First aired September to November 2018. Image Credit HULU

With a recent renewed U.S. interest in the Moon, lunar exploration has risen in the public consciousness. However, Mars has remained a strong constant in the public consciousness over the past year and Mars remains firmly implanted as the long-term goal of NASA.

For example, in 2018 there were two developments related to Mars that generated significant press coverage and public interest:

- **Liquid Water on Mars:** In July of 2018, the European Space Agency (ESA) announced the discovery of a liquid lake under the surface of the Martian south pole.
- **InSight:** The successful landing of the Mars InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) spacecraft occurred in November 2018.

Entertainment Industry

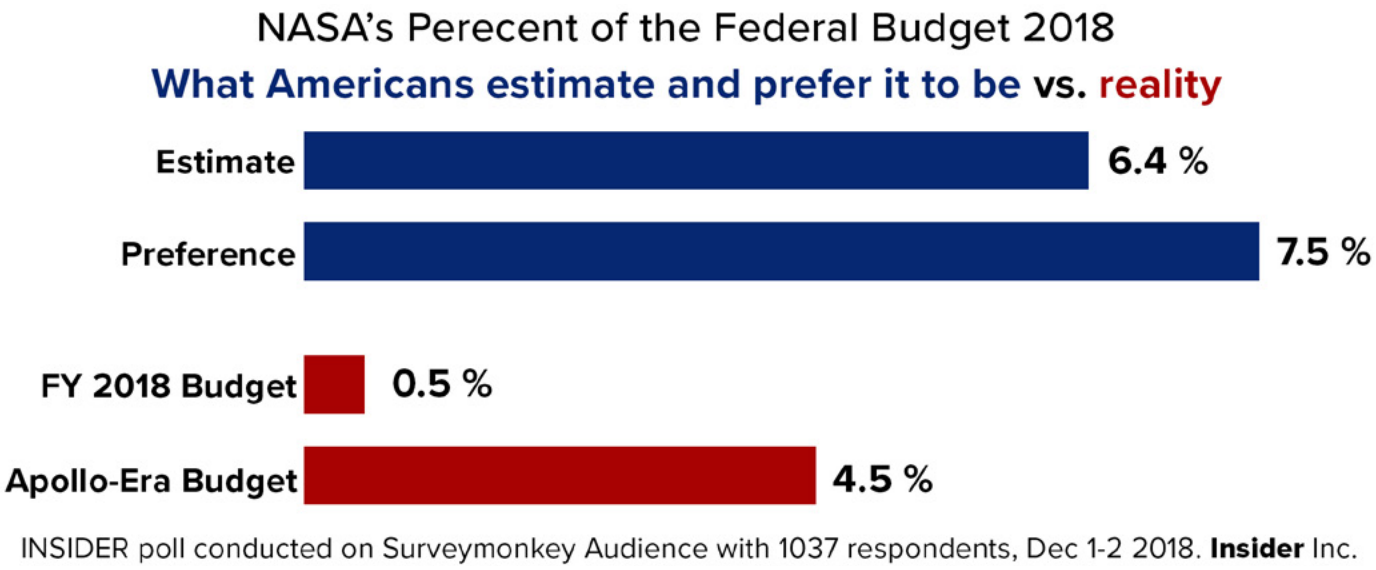
The entertainment industry remains infatuated with Mars related programming. Some of the projects that were released in 2018 or were in development include:

- **The First:** This television series aired on Hulu in September 2018. Created by Beau Willimon (writer, House of Cards), it stars award-winning actor Sean Penn. The First explores the challenges of taking the first steps toward interplanetary colonization in the near future. The first season focused on the human drama leading up to the launch to Mars, with the season ending as the crew was finally sent on their voyage to the red planet. Unfortunately, The First was not picked up for a second season.
- **Mars:** National Geographic aired season two of its television series Mars in November 2018. The series retained its duel format featuring a fictional storyline alternating with real life experts providing insights in a standard documentary format
- **Life on Mars:** John Krasinsky (creator of A Quiet Place) and his production company Sunday Night Productions will be producing a film version of a short story by Cecil Castellucci called We Have Always Lived On Mars that tells the story of a woman, who is a descendent of colonist who were abandoned by Earth years earlier, who finds one day that she can breathe the Martian atmosphere.

Public Polling

In 2018, Insider, a sister publication of Business Insider, conducted a poll of Americans to assess their opinions about the priorities of the United States space program as well as their understanding of the NASA budget.

https://www.businessinsider.com/nasa-budget-estimates-opinions-poll-2018-12#the-reality-of-government-spending-is-complex-and-contentious-5



The poll revealed strong support for NASA, but also exposed that the majority of Americans are unaware how small NASA funding actually is in relation to the rest of the federal budget. The poll revealed that over 60 percent of Americans did not know that NASA's budget was less than half of one percent of the overall federal budget. This is consistent with the 2013 Mars Generation Survey (https://www.exploremars.org/wp-content/uploads/2013/03/Mars-Generation-Survey-full-report-March-7-2013.pdf) that showed that on average, Americans estimated NASA's budget as 2.5 percent of the federal budget. (In this 2013 survey, participants were only given a range of between 0-6 percent from which to choose.)

Despite misconceptions about the level of NASA's budget, the 2018 Insider poll revealed that 85 percent of those polled believe that NASA's budget should be increased. This is consistent with the 2013 Mars Generation Survey that found that 75 percent of Americans believe that NASA's budget should be doubled.

Of those polled in 2018, over 57% believe that humans and robotic exploration of Mars should be the priority of the American space program. Compare this to the "National Opinion Poll on Mars, Robotics and Exploration" of 2016 that states that "84% of Americans agree or strongly agree that America leads the world in space exploration. Education level was not a factor in this perception. When asked if the United States should send humans to Mars, a majority of 64% of Americans agree or strongly agree in the mission."

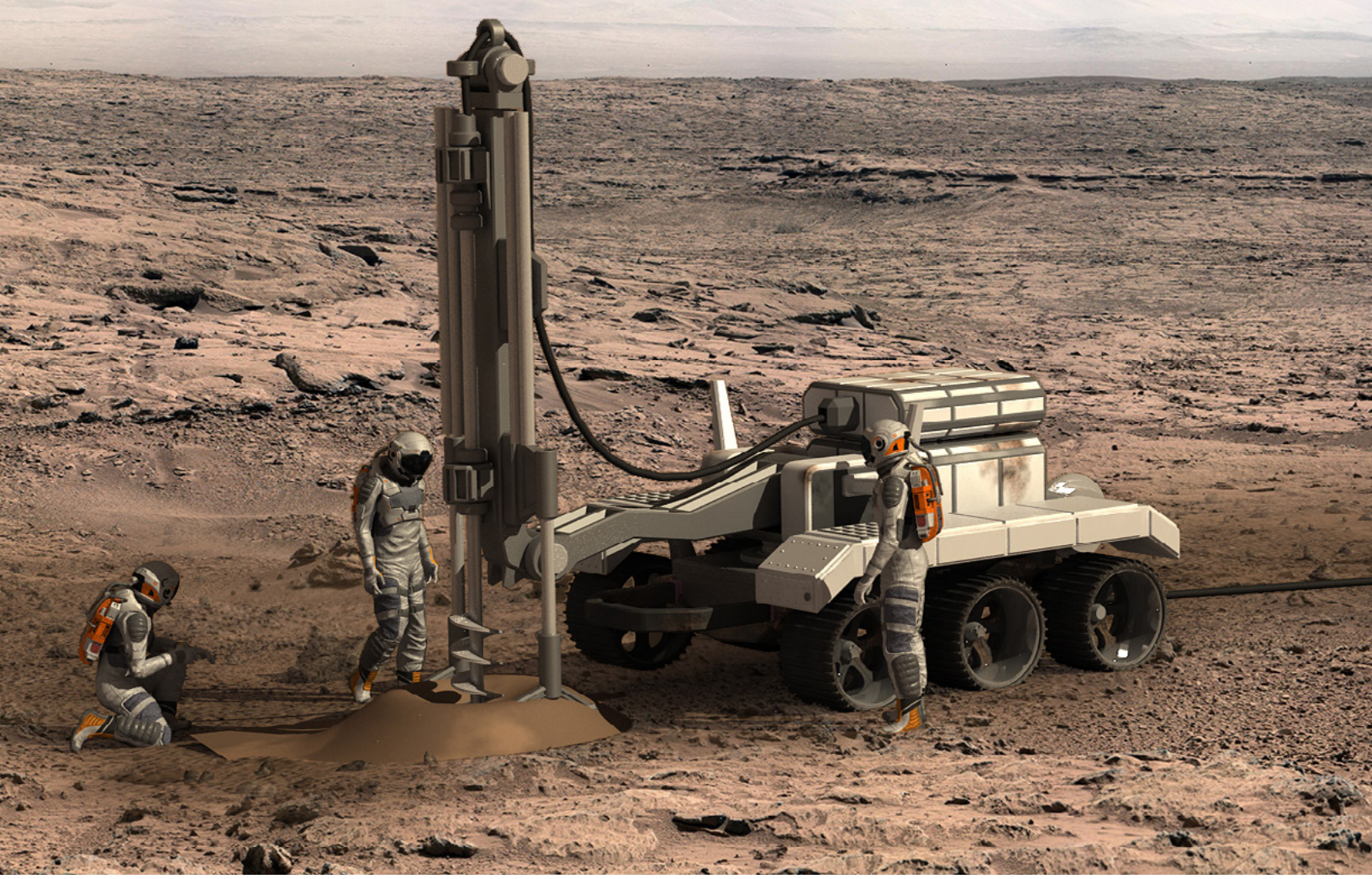
https://www.exploremars.org/wp-content/uploads/2017/02/SpaceExploration_National-Opinion-Poll-Report-5.7.Revised.Phillips.pdf

The 2013 Mars Generation poll also found that 71 percent of Americans believe that humans will land on Mars by the year 2033. This is consistent with the *NASA Transition Authorization Act of 2017* that was unanimously approved by both houses of Congress and signed into law. The Act requires that human missions to Mars should take place by 2033.

Business Insider Poll: https://www.businessinsider.com/nasa-budget-estimates-opinions-poll-2018-12#the-reality-of-government-spending-is-complex-and-contentious-5

National Opinion Poll on Mars, Robotics and Exploration of 2016: https://www.exploremars.org/wp-content/uploads/2017/02/SpaceExploration_National-Opinion-Poll-Report-5.7.Revised.Phillips.pdf

Mars Generation Poll of 2013: https://www.exploremars.org/wp-content/uploads/2013/03/Mars-Generation-Survey-full-report-March-7-2013.pdf



Bud On Mars Image Credit Budweiser

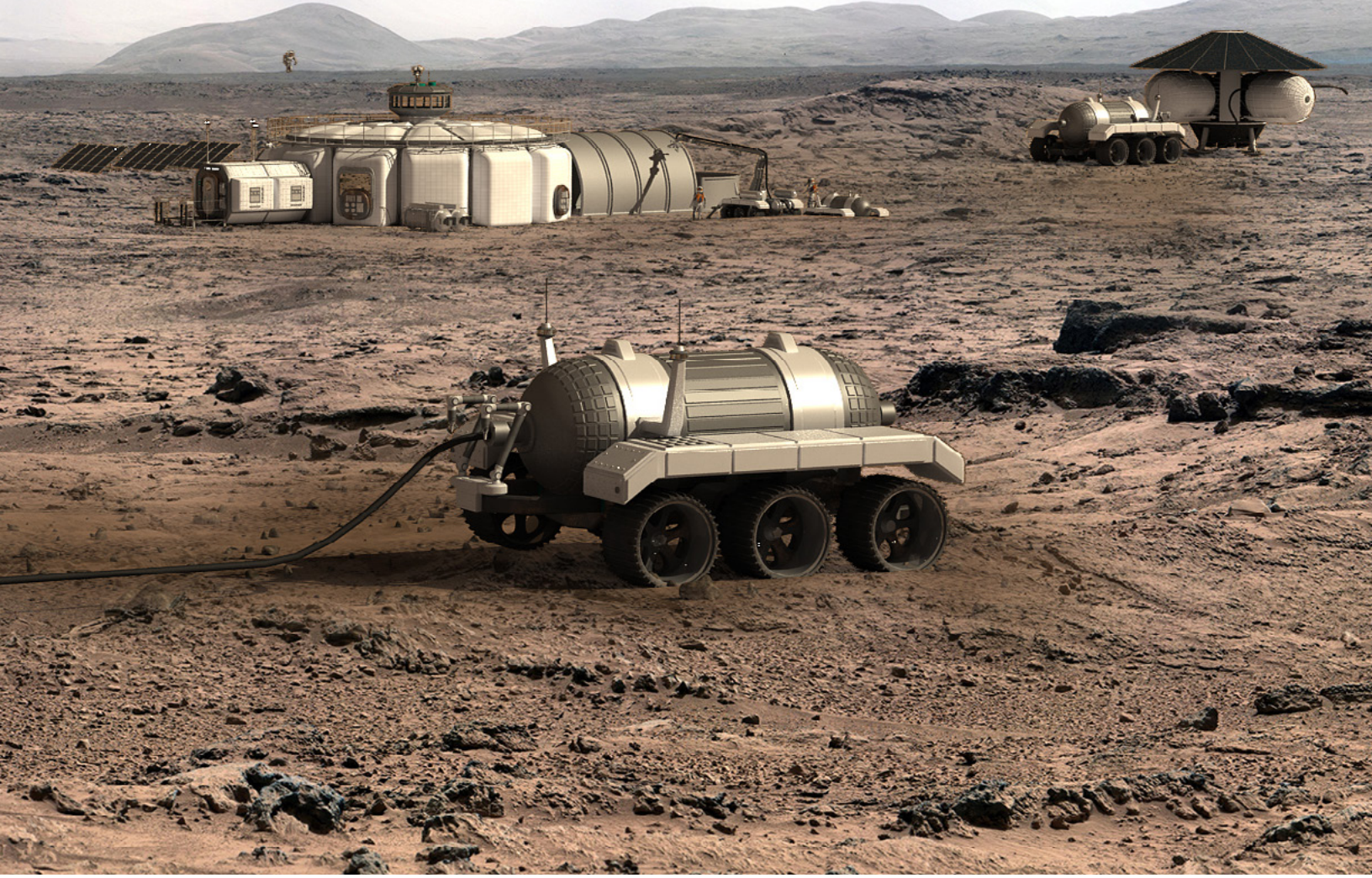
Marika Tarasashvili, an astrobiologist working on a project to develop grape varieties that can be grown on Mars. Image Credit: AFP

Re:Mars: While not exclusively Mars related, Amazon is launching the Machine learning, Automation, Robotics, and Space (re:Mars) event that will take place at the ARIA Resort & Casino in Las Vegas June 4-7, 2019. According to Amazon, "Business leaders and technical builders will learn, share, and further imagine how these four fields of study will shape the future of AI." Amazon hopes to take the lead in artificial technologies that will be vital in society and in space exploration. Even though the campaign is not specifically focused on Mars, the title of this project will nonetheless generate interest in Mars and the applications of AI on Mars.

Mars Booze:

- Budweiser: Budweiser continued its efforts to become the first beer on Mars with the launch of its second and third Barley experiments to the International Space Station in December 2018.

- Mars Wine: An initiative called IX Millennium in the country of Georgia hopes to advance the goal of producing wine one day on Mars. This a consortium of academic organizations, entrepreneurs, and government agencies that will be testing the growth of grape vines in simulated Mars soil, in harsh conditions, and with radiation exposure. Georgia boasts that it is the birthplace of wine and they hope to lead the way in viticulture when humans go to Mars.



Artwork by Bryan Versteeg, https://SpaceHabs.com

Recommendations

- ***Mars 2020 Rover:*** As NASA prepares to launch the Mars 2020 Rover next year, NASA, industry, and Mars advocates need to use this mission to build excitement regarding Mars exploration. Like the public campaign mounted when the Curiosity lander was launched and landed, the Mars 2020 Rover will provide a unique opportunity to reenergize the country and the world about the prospect of landing humans on Mars in the 2030s.

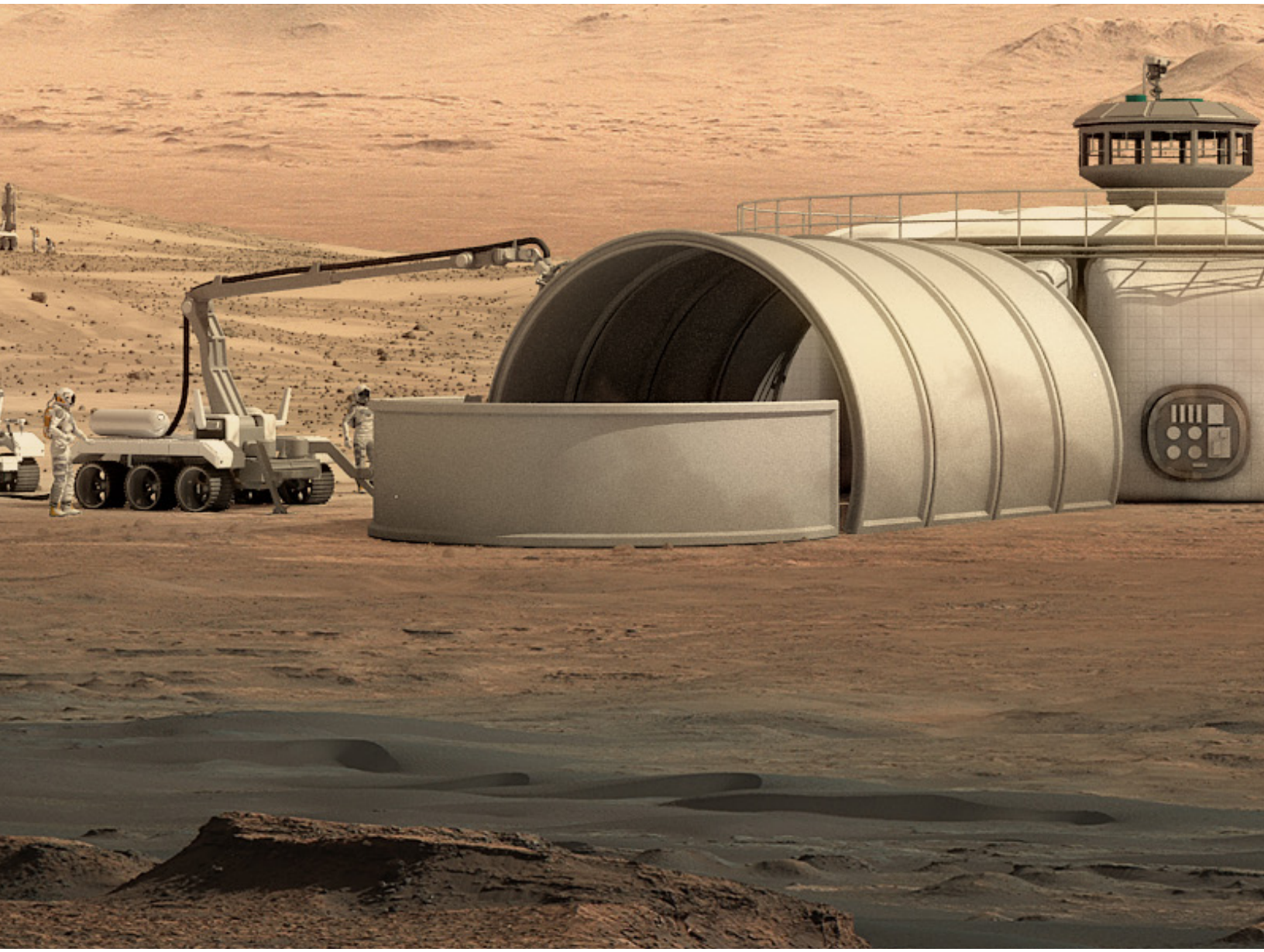
- ***2020 International Mars Missions:*** The Mars 2020 rover is not the only Mars robotic mission launching in 2020. The European Space Agency in partnership with the Russian space agency is launching the ExoMars lander and the United Arab Emirates is launching the Hope orbiter. China is also reportedly planning its first Mars mission as early as 2020 that will deliver an orbiter and rover to the red planet. With this unprecedented convoy of Mars missions being launched, it provides a unique opportunity to conduct a major international public engagement and STEM campaign.

- ***Better Outreach:*** In concert with the recommendations above, advocates of human missions to Mars need to undertake a continuous campaign of opinion pieces, lectures, Congressional and government briefings, and other forms of public and government outreach to highlight the need for human missions to Mars in the 2030s. This should include intensive social media, educational engagement, and building partnerships.

EXPLORE MARS

The HUMANS to MARS Summit 2020

Washington D.C.



#HumansToMars HTTPS://H2M.EXPLOREMARS.ORG