THE WHITE HOUSE

A New Era for Deep Space Exploration and Development

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THE WHITE HOUSE

NATIONAL SPACE COUNCIL

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*"Beginning with missions beyond low-Earth orbit, the United States will **lead** the return of humans to the **Moon** for long-term exploration and utilization, followed by human missions to **Mars** and other destinations."*

– President Donald J. Trump

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Introduction

At the sixth meeting of the National Space Council on August 20, 2019, the Council adopted a set of recommendations, including a recommendation that directed the National Space Council staff, in consultation with National Space Council members and the Users' Advisory Group, to present to the Chairman of the National Space Council a Moon-Mars Development Strategy. This strategy was to include low-Earth orbit commercialization, robotic and human exploration, national security capabilities, and international cooperation for science, safety, security, and economic growth.

The strategy delineated in this paper supports an ambitious vision for human space exploration and development. This vision is one in which there is a sustainable human and robotic presence across the solar system — an expanding sphere of commercial, non-governmental activities in which increasing numbers of Americans live and work in space. This vision begins with a campaign to utilize Earth's orbital environment, the surface and resources of the Moon, and cis-lunar space to develop the critical technologies, operational capabilities, and commercial space economy necessary for a sustainable human presence on the Moon, Mars, and beyond.

U.S. space exploration efforts impact and aid multiple national interests, including the economy, national security, scientific advances, and diplomacy. The landscape has changed drastically since the early beginnings of the Space Age. Current space exploration efforts involve a greater number of nations and private sector actors, and as a result, the nature of leadership in space has evolved. The challenge in this new era is not simply to achieve what others cannot but to provide opportunities for others to partner with us. Although NASA is, and will remain, the primary United States Government entity for civil space exploration efforts, other departments and agencies have increasingly important roles to play in space.

The American way of life is reliant on space activities—and we truly are a spacefaring Nation. However, space is not subject to claims of sovereignty or other traditional means of protecting national interests in a shared domain. As a result, the United States will lead our allies and other like-minded nations, while dissuading adversaries, in order to preserve and advance U.S. national interests in space. In doing so, United States Government space efforts will include commercial and international partners in the development and exploration of space.

Space development, including industrial-scale commercial activities, cannot be accomplished by the government alone. An internationally competitive U.S. commercial space sector is a foundational requirement for U.S. space leadership. Although government resources are necessary to establish space exploration beyond low-Earth orbit, its long-term sustainability is unlikely without the efficiencies and innovation of the private sector. As a result, the government will continue efforts to reform, streamline, and eliminate unnecessary regulatory burdens that may hinder U.S. space commerce in order to ensure that American companies can effectively compete in the global marketplace.

To execute this vision requires a secure international environment that is conducive to U.S. commercial growth. The United States Space Force (USSF) does not have a direct role in the civil exploration and development of space per se – its responsibilities focus on organizing, training, and equipping the forces needed to support combatant commands and ensure unfettered access to and the use of space by the United States and its allies and partners. However, activities such as space transportation and logistics, power, communication, navigation, and space domain awareness, are of dual-use value to all space sectors – civil, national security, and commercial. The development of civil and commercial best practices can lead to norms of responsible behavior that improve international stability and transparency for all space activities. The important supporting roles of the Departments of State, Defense, Commerce, Transportation, Energy, and Homeland Security in space exploration and development are among the major reasons the United States takes a whole-of-government approach to its space activities.

Background

Before formulating a Moon-Mars Development Strategy, it is necessary to review briefly the National Space Strategy (2018) and Space Policy Directive 1, "Reinvigorating America's Human Space Exploration Program" (2017). The National Space Strategy approved by the President in March 2018 prioritizes American interests first and foremost by emphasizing peace through strength in the space domain. In doing so, it requires a dynamic and cooperative interplay between the national security, commercial, and civil space sectors. The purpose of this integrated effort is to ensure that the United States has unfettered access to and the freedom to operate in space, in order to advance American security, prosperity, and scientific knowledge.

The National Space Strategy consists of four pillars in a unified, whole-of-government approach:

- **Transform to more resilient space architectures:** The United States will accelerate the transformation of its space architecture to enhance resiliency, defenses, and the ability to reconstitute impaired capabilities.
- **Strengthen deterrence and warfighting options:** The United States will strengthen U.S. and allied options to deter potential adversaries from extending conflict into space and, if deterrence fails, to counter threats used by adversaries for hostile purposes.
- **Improve foundational capabilities, structures, and processes:** The United States will ensure effective space operations through improved situational awareness, intelligence, and acquisition processes.
- **Foster conducive domestic and international environments:** The United States will streamline regulatory frameworks, policies, and processes to leverage and support U.S. commercial industry more effectively, and will pursue bilateral and multilateral engagements to enable innovative private sector growth, human and robotic exploration, promote burden sharing, and marshal cooperative threat responses.

The focus of this National Space Strategy on national security provides a foundational perspective and rationale for all U.S. space activities, including civil space exploration and commercial development. There are at least two reasons for this connection between national security and civil elements. First, the technical capacities and key technologies that enable both civil and military space activities come from the same industrial base and skilled workforce. Second, the creation of conducive domestic and international environments is necessary for civil space activities, and those activities can, with partners and like-minded countries, help create a more stable and predictable environment that enhances national security and economic prosperity.

The Trump Administration has recognized that in order to be stable and sustainable over the long-term, America's space efforts must be strongly linked to, and supportive of, enduring national interests. From economic prosperity and national security to science and diplomacy, space activities provide practical as well as symbolic benefits to the nation. Space exploration, human space exploration in particular, has often been strongly shaped by U.S. geopolitical interests. In turn, space cooperation has reflected and followed those interests.

Space Policy Directive 1, "Reinvigorating America's Human Space Exploration Program" (signed by President Donald J. Trump on December 11, 2017) states that the United States will:

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

The Vice President and the National Space Council expanded on this directive at the fifth meeting of the National Space Council on March 26, 2019, in Huntsville, Alabama. At this meeting, the Council adopted a recommendation that states:

> *Consistent with the overall goals of SPD-1, the United States will seek to land Americans on the Moon's South Pole by 2024, establish a sustainable human presence on the Moon by 2028, and chart a future path for human Mars exploration. NASA's lunar presence will focus on science, resource utilization, and risk reduction for future missions to Mars.*

Although many of the technical goals for the Moon and Mars are not new, the requirements for such missions to be sustainable, to involve commercial and international partners, and to include resource utilization, are new to U.S. national space policy. The 2024 landing date has provided a strong and immediate focus to NASA's human spaceflight efforts. In addition, the April 6, 2020 Executive Order on "Encouraging International Support for the Recovery and Use of Space Resources" made it the policy of the United States to encourage international support for the public and private recovery and use of resources in outer space. Over a longer time horizon, the demands of sustainability will have just as critical an influence on the nation's space enterprise. Broadly defined, the long-term sustainability of space activities is the ability to indefinitely, and responsibly, explore and use space.

The term "sustainable" can have different meanings, depending on the context. For example, financial sustainability is the ability to execute a program of work within budget levels that are realistic, managed effectively, and likely to be available. Technical sustainability requires that operations are conducted repeatedly at acceptable levels of risk. Proper management of the inherent risks of deep space exploration and settlement is the key to making those risks "acceptable." Finally, policy sustainability means that the program's financial and technical factors are supportive of long-term national interests, broadly and consistently, over time. Robotic space exploration, for example, has benefited from a constancy of purpose driven by priorities identified by the National Academies through their Decadal Surveys. Similarly, the U.S. Armed Forces have supported scientific exploration and helped ensure the free flow of trade and commerce, while performing their fundamental mission of protecting the nation. Although the nation has healthy debates over the cost, size, capabilities, and duties of our Armed Forces, it does not question whether the United States should maintain such forces. Long-term deep space exploration and development should seek to have a similar level of policy sustainability. It can do so by ensuring such efforts promote and strengthen the technical, economic, and foreign policy objectives of the United States and its allies.

A New Vision for a New Era

The United States is crucially reliant on space systems, and the future sustainability and governance of space activities are a key strategic interest for the nation. If we are to have an effective American space strategy, we need to align our policies, programs, and budget with enduring national interests that span multiple administrations and Congresses. This means looking beyond individual missions and asking what values will be, and should be, part of any human future in space. The Trump Administration seeks to ensure these include core American values we hold today – such as democracy, human rights, constitutional governance, the rule of law, and free markets. To that end, shaping the international environment and enabling routine operations out to the Moon – with Mars as a horizon goal – would greatly enhance long-term U.S. national security, commercial and foreign policy interests in space.

The Moon is more than a physical destination. It is essentially humanity's eighth continent, carved off our planet billions of years ago. It is a means of answering scientific questions, providing space operations with sustaining resources, creating new technical capabilities, training individuals and organizations, and forging new international relationships within a broad and adaptable space infrastructure. Our immediate purpose should be two-fold: to develop the critical technologies and capabilities that will enable human missions to Mars, and to create the strategic national capability to operate on another planetary surface, starting with the Moon. These capabilities will enable the United States to lead international and commercial endeavors for space exploration and development. Alternatively, their attainment by a malign competitor could gravely harm the international position and technical leadership of the United States. Although many countries may choose to operate in space, including potential adversaries, U.S. friends and allies should be able to rely on the abiding presence of the United States.

Geopolitical interests and objectives provide the historic model and rationale for practically all U.S. human spaceflight missions. Those interests include security, commerce, science, and international leadership, or any combination thereof. The next steps beyond low-Earth orbit will require cooperation among international partners for both practical and political reasons. The U.S. commitment to lead a multinational effort leveraging public-private partnerships forward to the Moon is a symbolic and practical first step, as well as a means of creating a broader international framework conducive to the interests of the United States and like-minded countries.

The geopolitical benefits of engagement with friendly, growing space powers can support more ambitious space exploration efforts than science alone might justify. These efforts can, in turn, benefit the U.S. commercial space sector. For example, providing commercial cargo delivery to the lunar surface could be an attractive market for U.S. industry. Commercial firms could potentially provide communications and power to lunar surface operations. The long-term focus on Mars and other deep space destinations provides a structure to drive the definition and implementation of capabilities and research on and around the Moon, such as nuclear power sources, long-term habitation modules, and robotics to identify, extract, and utilize local resources.

An understanding of the criticality of space activities to the life of the nation, and the need to secure U.S. interests in space, necessitates a strategy of space exploration and development that extends our presence from low-Earth orbit, moves forward to the Moon for a new era of utilization, and reaches toward Mars and beyond. It is not merely machines and astronauts that constitute U.S. space activities, but our values as well. As on Earth, the rules of the space domain will be created by those with the courage to go and the conviction to stay. The United States and other freedom-loving countries must drive and craft humanity's future in space. The United States cannot, and will not, cede its role as a leader of spacefaring nations.

President John F. Kennedy challenged the United States to reach the Moon, and, for his generation, that was an enormous, risky, and daunting challenge. President Donald J. Trump has challenged the United States to develop the Moon, Mars, and other celestial destinations, which is a modern-day challenge no less daunting. By accepting this bold call to action, we will enable future generations to build on our accomplishments, with the goal of making travel throughout the solar system a normal part of the human experience with large numbers of free people living and working in space.

The U.S. vision for space is one in which there is a sustainable human and robotic presence across the solar system, and where there is an expanding sphere of commercial, non-governmental activities, with increasing numbers of Americans living and working in space. This vision begins with a campaign to utilize Earth's orbital environment, the surface of the Moon, and cis-lunar space to develop the critical technologies, operational capabilities, and commercial space economy necessary for a sustainable human presence on the Moon, Mars, and beyond.

The United States and its partners demonstrated the ability to maintain a permanent human presence in space with the International Space Station. This presence, however, still depends on support from Earth. As a next step, the United States should seek to develop the Moon, use it as a proving ground for technologies and processes that will provide greater independence from Earth through extraterrestrial operations, such as manufacturing, mining, and conducting cutting-edge lunar science, which will enable America and its commercial and international partners to mount historic human missions to Mars and beyond. In 2006, John Marburger, President George W. Bush's Science Advisor, articulated the case for developing the Moon:

> *"The Moon is the closest source of material that lies far up Earth's gravity well. Anything that can be made from lunar material at costs comparable to Earth manufacture has an enormous overall cost advantage compared with objects lifted from Earth's surface. The greatest value of the Moon lies neither in science nor in exploration, but in its material. ... I am talking about the possibility of extracting elements and minerals that can be processed into fuel or massive components of space apparatus. The production of oxygen in particular, the major component (by mass) of chemical rocket fuel, is potentially an important lunar industry."*

This focus on further extending an extraterrestrial human and robotic presence and on the development of commercial space industries makes the Artemis Program much more than a repeat of the Apollo Program. A serious, determined approach to lunar development requires a series of pre-positioned logistics packages. A combination of 3-D printing, telerobotics, and artificial intelligence could enable pre-positioning the equivalent of a small Antarctic scientific station. Newly arrived astronauts should have a substantial amount of resources already available and be able to spend their initial weeks building out the initial infrastructure for larger, future development teams. Initially, government support for research and demonstration will be needed to determine the feasibility of extracting useful resources, such as water. As soon as possible, and in accordance with the Executive Order on "Encouraging International Support for the Recovery and Use of Space Resources", commercial firms should take over routine operations to provide consumables like water, hydrogen, oxygen, and utilities such as power and communications. The transition to private sector responsibilities will represent an important step beyond space exploration to development and industrialization.

Landing American astronauts on the Moon in 2024 is just the beginning of this great adventure. The following 2 or 3 years should see a very substantial increase in the capabilities of the lunar astronauts, the number of people working on the Moon, and the robustness of the space logistics systems bringing people and cargo back and forth on a routine basis. A large amount of the early work on the Moon should be pioneering and maturing efforts that make expansion to Mars and beyond more practical. The Moon is only a few days from Earth, while Mars is a months-long journey. The Moon should be the proving ground for learning how to work far from Earth for long durations, to use local resources to reduce, and eventually eliminate, the need for supplies from Earth, and to use robotics to pre-position and resupply surface facilities.

An Ambitious and Sustainable Strategy

The extension of an American presence beyond Earth orbit, in concert with commercial and international partners, will be one of the most significant undertakings in human history. It will require a whole-of-government approach to develop the necessary capabilities, a conducive regulatory environment for private investment and operations, and diplomatic engagement to create international partnerships with existing and emerging spacefaring states.

Although NASA is, and will remain, the leader for U.S. government space exploration efforts, other departments and agencies will have increasingly important roles in space. Nearly every United States Government department and agency has potential equities in the utilization and development of space. The National Institutes of Health, the National Science Foundation, and the National Institute for Standards and Technology already support research on the International Space Station. The Department of Energy will be critical to the development of space nuclear power systems such as fission reactors on the Moon and Mars as well as space nuclear propulsion systems that may carry crews to Mars. The Department of Transportation will provide efficient and responsive commercial space launch and reentry regulations. The Department of Commerce will be the lead government advocate for growing space commerce both on Earth and in space. The Department of Interior will help leverage its terrestrial experience in mining and other relevant areas to identify and manage the private use of resources. The Department of State will lead diplomatic efforts to enhance stability in outer space through transparency and confidence building measures, guidelines for responsible behavior in outer space based on U.S. best practices, and bilateral and multilateral instruments that reflect U.S. values and policies. Through its public diplomacy activities, the Department of State can help convey and advance U.S. space goals, objectives, and plans with foreign countries.

By accelerating the commercialization and industrialization of space, the United States will grow the sphere of human activity beyond the Earth, forge new capabilities for sustainable expansion into the solar system, and provide benefits for enhanced life and commerce for all of humanity to enjoy. This expansion will occur over decades and build on the experiences of the more than 60 years since the start of the Space Age. The roles of governments and the private sector will change as technologies, costs, and markets evolve. Space activities that require government support and infrastructure today can become market-driven tomorrow. Even where government remains the sole or primary source of demand, commercial contracts for goods and services can be used to deliver results at lower cost and higher efficiency. In areas such as scientific exploration where there may be no market incentives, the government will continue to play a leading and pioneering role while seeking to leverage and find synergy with commercial capabilities. Where space resources, broadly defined, are at stake the private sector will likely be the more efficient exploration leader, and the government should take actions to support such activities.

In contrast to the Apollo program, a strategy for space exploration and development in this new era does not end with a single event, such as humans landing on the Moon or reaching the surface of Mars. An ambitious and sustainable strategy should be aligned with enduring national interests, be affordable, and be technically sound. To that end, there are three major areas of effort in going from low-Earth orbit, to the Moon, and then to Mars: commercialization of low-Earth orbit, returning to the Moon to stay, and extending a human presence to Mars using the lessons learned from and resources gained by the exploration and development of the Moon.

Commercialization of Low-Earth Orbit

As the United States leads humanity in deep space exploration, a long-term presence in low-Earth orbit will remain vital. Using the International Space Station and the Space Shuttle, humans working in low-Earth orbit have shown their effectiveness in technology development and testing, crew training, and scientific research. However, the International Space Station has a finite lifespan, and the United States and our international partners do not wish to build a duplicate of this unique million-pound facility. Instead, a variety of future space stations, in diverse orbital locations, commercially owned and operated, will succeed it. Removing regulatory barriers for the private sector to purse revenue-generation activities and conduct research in microgravity and allowing companies that invest in such activities to be able to fully retain their intellectual property, is paramount to building a pipeline of research and development in low-Earth orbit. The United States Government will continue to be a major customer, or even an anchor tenant, of new low-Earth orbit stations, which will be necessary to facilitate an increasing range of activities devoted to non-NASA government and non-government customers.

Commercial orbital platforms of the future, some of which will be human-tended, will be present in Earth orbit and potentially around the Moon to facilitate advancements in fundamental science, space communications, propellant depots, and research and development facilities, including astronaut training and human health research. Such stations will help provide alternative concepts of operations and in-space manufacturing capabilities that can facilitate the pre-positioning of assets to offset costly terrestrial launch requirements for future missions to the Moon and Mars.

Returning to the Moon to Stay

The Moon is closer to Earth than any other planetary body, and thus the logistics and transportation systems associated with missions to the Moon are more feasible, both technically and economically, than those required for a direct human mission to Mars. In addition, lunar exploration will reduce overall risks for Mars through the development and demonstration of new space systems necessary to operate on a planetary surface.

In contrast, a present-day human mission to Mars would be exceedingly risky and expensive. With current propulsion capabilities, a one-way journey to Mars requires up to 8 months of deep-space travel, with roundtrips exceeding 2 years. Although some private entrepreneurs might accept the inherent risks of deep space and systems reliability, if an emergency occurs during some phases of flight, it may not be possible for the crew to return safely. Entry, descent, and landing on Mars for heavier crewed vehicles have never been demonstrated and will require significant testing and precursor cargo landings prior to the first human mission. The multi-year duration of a Mars mission requires mitigation of harmful effects from radiation and reduced gravity in ways that are not yet fully understood.

As meaningful human lunar surface operations begin, the length of stays, variation of activities conducted, size of facilities, and number of habitants can increase. With the help of advanced research and development on Earth and in low-Earth orbit, the next lunar explorers will use longer-lasting and more reliable means of habitation, life support, power generation, transmission, storage, surface transportation, and resource extraction and utilization. Surface mobility will enable broader exploration, and reusable vehicles will ferry astronauts and cargo between the lunar surface and the lunar Gateway. Moreover, the development and use of interoperable commercial and international partner systems will be a critical part of lunar activities from the beginning.

Leveraging experience gained through lunar surface operations under the Artemis Program, future Mars missions will utilize in-situ resources, regenerative environmental control and life support systems, nuclear power generators, and pressurized rovers. These same systems are required for the lunar surface and will be demonstrated there first. A crewed lunar field station, growing from the Artemis Base Camp on the Moon, will demonstrate these and other capabilities necessary to take the next giant leap to extend a human presence to Mars while enabling unprecedented human and robotic lunar exploration.

Lunar regolith, especially areas containing water ice at the poles, has yet to be fully characterized, but we know it harbors resources that can provide energy, life support, and spacecraft propellant. Learning how to extract, process, and use these resources will enable explorers to reduce the mass required to support lunar and, subsequently, Martian logistics. This ability to partially, and perhaps one day fully, “live off the land” will be integral to a sustained presence on the Moon and Mars.

In addition to technical rationales, the Moon is also an important strategic and political destination. Ensuring the United States and its partners maintain a presence in areas of strategic importance is crucial to safeguarding our ability to operate anywhere in space, from low-Earth orbit to the lunar surface to Mars. American astronauts left the last boot prints on the Moon almost 50 years ago, no other nation has ever landed humans on a celestial body, and few other nations have even been able to send robots successfully to the lunar surface. Being able to participate in lunar exploration and development is immensely challenging, yet feasible, for other spacefaring nations. Thus, it is attractive to them and an opportunity for the United States to foster a more secure and stable regime for space activities.

Extending a Human Presence to Mars

Mars is the next destination following the demonstration of a sustainable lunar surface presence. Robotic exploration programs have found that the Martian surface, like the Moon, contains many of the necessary resources to sustain a long-term human presence. Mars shows evidence of high concentrations of solid water ice across most of its surface, and an atmosphere that, although thin, can be used to produce vital resources, such as propellant, without complex regolith mining and extraction equipment. Many of the same systems developed for resource extraction and use on the Moon can be adapted for Mars.

Discoveries and advances made on the Moon in the coming years will heavily influence the design of crewed missions to Mars. These factors include questions about the availability and cost of propellant in space, the feasibility of in-situ resource utilization, in-space manufacturing and assembly systems, and advanced space nuclear propulsion. Work over the next decade in low-Earth orbit and on the Moon should focus on how to reduce drastically the cost and complexity of human missions to Mars, while increasing the likelihood of success, safety, and sustainability.

The initial and long-term exploration and development of the Martian surface will likely mirror lunar exploration in many ways. For example, robotic missions to pre-position resources will be a necessity for the success of the first and subsequent crewed missions. These resources might include pressurized rovers, habitation modules, supplies, and an ascent vehicle. Local resource utilization, power generation, and other means of self-sustainment will be critical for human missions to establish any long-term presence on Mars.

If the United States can establish a long-term human presence on the Martian surface, it will have demonstrated the technology and expertise to begin to explore other destinations safely. Further exploring deep space, finding and utilizing resources, and ensuring a conducive environment for the United States and like-minded countries to peacefully explore and develop the solar system will help to permanently secure American interests and values in the space domain.

The Potential for Deep Space Science

The first Apollo samples and geophysical data collected on the Moon remain scientifically interesting after more than 50 years. However, these initial investigations, across areas smaller than the National Mall in Washington, D.C., have generated vast new questions for future explorers to help answer. Great potential exists for conducting unique scientific investigations in deep space, using both human and robotic endeavors. In addition to new discoveries regarding the evolution of the Moon and the terrestrial planets, Apollo's scientific results alone offered unprecedented insights into the early history of the solar system and Earth itself, the origins of life on Earth and potentially on Mars, and the history of the Sun and its interaction with the Earth. A continued human presence on the Moon, and eventually Mars, will provide opportunities for fundamental advances in fields ranging from observational and radio astronomy to materials science and biology, as articulated through numerous community assessments by the National Academies, the Lunar Exploration Analysis Group, and the Mars Exploration Program Analysis Group.

Education and the U.S. Workforce

The exploration and development of space is a multi-generational endeavor. The future workforce needs of the United States and its international partners are ever-changing. The necessary skills encompass virtually every scientific, technical, and engineering discipline, as well as leadership and management skills for the highly complex, multi-disciplinary projects inherent to the space industry. Entirely new skills will also be needed that may have terrestrial analogies but that cannot be fully duplicated on Earth. During the Apollo program, astronauts had to learn how to land a vehicle on the Moon that could not operate in the Earth's gravity. Similarly, the skills needed to operate a lunar or Martian base have been researched and analogs have been tested, but we will not truly know what skills are needed until we actually try.

Space exploration and utilization directly supports the long-term strategic interests of the United States. As such, developing and maintaining a skilled workforce—one that is diverse and inclusive—to perform these long-term exploration and development activities is also of strategic interest. Ensuring the country's education system is equipped to provide the skills necessary to perform this work is critical to the quality of life of our citizens, to our ability to be internationally competitive, and to our ability to ensure the security of the nation and the world. Our ability to lead in space exploration and development will depend on how well the United States is able to educate, train, and employ future generations of American space workers. Current shortages of trained employees in select areas (e.g., systems engineering, computer engineering, and cybersecurity) are a warning that the United States may lack the incentives and mechanisms to prepare the workforce the nation needs.

Although space exploration and development is and should continue to be an international endeavor, the dual-use nature of many space technologies and capabilities means the United States needs educated and trained Americans to work on the most advanced space capabilities. There is a high rate of international students receiving graduate engineering degrees in the United States and then returning to their home countries. This is a tremendous testament to the quality of top-level U.S. universities and is beneficial to U.S. universities, but the United States needs to remove barriers and create incentives for U.S. students to pursue these degrees as well. Also, for those U.S. students who are obtaining these degrees, the U.S. space industry needs to do a better job of attracting top talent for which they often compete with other industries.

Some of the most powerful motivations for students to pursue technical degrees are the prospect of being challenged to excel, the opportunity to make a difference in the world, and meaningful participation in a great enterprise. As the United States seeks to educate and engage the "Artemis Generation," we need to not only describe exciting technical challenges, but also to illustrate the opportunities and pathways by which new generations will personally experience and contribute to this singular adventure. The exploration of the Moon and Mars, beginning with the Artemis program, and stretching forward to the development of the inner solar system, has the potential to motivate future generations of Americans, as well as international students, to make that vision of tomorrow a reality.

The Role of Government

In the past, the United States Government took the responsibility for all aspects of human space exploration and development—defining the missions, designing the architectures, setting technical specification, overseeing industry contracts, and directly conducting operations. The government will continue to have a central role for the foreseeable future, however, but in partnership with private industry. In the future, the government will take on more indirect roles, such as being a patron of research and development, a first buyer or anchor tenant for space goods and services, and a regulator as necessary for public safety or national security reasons and to fulfill international obligations.

The success of American space exploration and development in this new era will require a whole-of-government approach. Five primary government roles are crucial to executing the vision described in this paper:

1) Promote a secure and predictable space environment for the long-term sustainability of space activities;
2) Support the development of commercial activity and industry in space;
3) Support research and development of new space technologies;
4) With commercial and international partners, create infrastructure needed for space exploration and development; and
5) Support advanced space research by public and private sector U.S. research communities.

1) A Secure and Predictable Space Environment

The United States Government, in concert with industry, should create and maintain a supportive regulatory and physical environment for space activities. Without an assurance of safe operations; clear, sensible regulations; manageable risks; and rights to generate profitable revenue, viable economic activity is unlikely to occur.

Space Policy Directive-3 directs the Department of Commerce to manage debris mitigation efforts and space traffic as well as create a new protocol of standard practices for safe space operations. Departments and agencies should improve accuracy of orbital data on space objects, including debris, and enhance the practice and utility of sharing orbital information on space objects and debris.

The United States Government should meet its international obligations without complex, new regulatory structures, and focus on reducing barriers to developing new commercial space activities wherever possible. In areas where relevant law, policy, and/or regulation currently exists, improvements must still be made to maximize U.S. competitiveness and drive innovation. Some examples include space traffic safety and space situational awareness, on-orbit servicing and manufacturing, export controls, launch licensing, the extraction and utilization of space resources, and meeting the radio frequency spectrum needs of space applications. To that end, the National Space Council has tasked the Departments of Commerce and Transportation to provide a roadmap to enable all commercial space activities to receive authorization under appropriate frameworks.

2) *Development of Commercial Activities and Industry in Space*

The United States Government should stimulate demand for space products and services consistent with civil and national security missions. Although the United States Government cannot, and should not, be the sole customer for all space capabilities, the government has a role in facilitating the development of these markets. The United States Government can help increase international demand for space-derived products, particularly on the part of developing countries. For example, space-based communication, navigation, remote sensing, and related services can help improve the productivity of industries in developing countries. Supporting the space needs of developing countries also provides an alternative to states that might otherwise turn to malign actors who may burden them with excessive debt and engage in other detrimental practices.

The United States Government should consider commercial procurement tools to be the normal way of doing business, rather than the exception. Government departments and agencies need to become more agile and responsive to exploit private sector offerings, especially for missions and capabilities that do not require major new developments.

The United States Government should continually seek to lower barriers to entry to allow greater involvement of small businesses in space activities. This includes continuously updating export controls and other restrictions on U.S. industry to keep American companies competitive in the international market while bolstering national security. Further improvements related to intellectual property rights, liability protections, security measures, and other regulations can strengthen space commerce without increasing the risk to the public or creating unfair trade practices.

Additional efforts should broaden the scope of traditional aerospace industries to include new applications for space technologies and expand space capabilities by infusing technologies from non-traditional but promising fields, such as robotics, artificial intelligence, quantum applications, and additive manufacturing, which have much to offer the space community. Other fields, such as medicine and materials science, can bring research activities to sustain commercial platforms and enable in-space manufacturing.

3) *Research and Development for New Technologies*

The United States Government should encourage and support research and development for new technologies to enable lower cost commercial activities in space. Concurrently with efforts to improve the physical, regulatory, and business environments in space, the United States Government should continue technical efforts that will create new opportunities for private sector innovation.

Investments in research and development alone are not enough; new contracting mechanisms and the use of existing other transaction authorities for early-stage partnerships can help to accelerate the introduction of innovative technologies into operational use. Technology transfer and licensing practices should be reformed to match more closely the speed of private sector, entrepreneurial, and investor-driven decision-making.

The United States Government should enable the infusion of innovative approaches from commercial and international partners. A critical objective of human spaceflight is to make it routine and repeatable with an acceptable level of risk at lower cost. Examples of potentially routine operations, beyond launch and reentry, include in-space rendezvous, refueling, and autonomous propellant production.

4) *Investments in Private Space Infrastructure*

The United States Government should support the development of private, investor-based space infrastructure by being a reliable customer. Private infrastructure, both in space and on Earth, can support United States Government space activities at lower cost than if the government were the sole owner and operator. Regular flight opportunities and innovative contracting mechanisms can support the development of platforms and other infrastructure to serve multiple purposes, thus sharing fixed costs across a variety of customer communities.

The United States Government should further improve how it coordinates and communicates research and development priorities to the private sector. For example, a national strategy for microgravity research and development would be of value as industry seeks to develop commercial platforms as successors to the International Space Station.

Infrastructure priorities should include consideration of the long-term financial and technical sustainability of space exploration and development. In particular, the U.S. government should encourage the creation and testing of scale versions of the technologies, instruments, and processes that will enable Moon, Mars, and asteroid surface operations. In-situ resource utilization technologies for extraction of resources to create potable water, breathable air, spacecraft propellant, and other necessities are particularly critical. New options for surface power to survive harsh lunar nights, such as space nuclear fission reactors, will be vital for long-term operations on the Moon and Mars. New approaches to surface transportation and spacesuit design, particularly related to dust rejection, will be key to maximize opportunities for exploration and scientific returns.

5) *Support of Advanced Space Research Activities*

In partnership with the private sector, the United States Government (including its complex of U.S. National Laboratories and other Federally Funded Research and Development Centers) should encourage and, as necessary, financially support advanced space research activities throughout the U.S. public and private research communities. The current foundation of scientific and engineering knowledge about the Moon and its resources is the result of federal funding of academic and private research activities on Apollo samples and geophysical data. Private sector research capabilities and funding will be crucial to the commercial development of space as the United States and its partners gain new knowledge from exploring the Moon, Mars, and other destinations. Universities can make important contributions to the development of new technologies, private space infrastructure, and advanced space research. Universities have unique networks for expertise, both within the United States and internationally, that can enhance space exploration and development. Individual university laboratories and experts have traditionally been a part of civil, national security, and commercial space projects and programs. However, consortiums of universities might address particular challenges, such as deep space medicine, automated in-situ resource extraction, and artificial intelligence for high-reliability remote operations.

Concluding Observations

Some people argue that humanity is destined to develop space settlements and become a "multi-planetary species." Although this is certainly an exciting possibility, it will depend on our ability to use in-space resources and live independently from Earth's support and environment. It will also depend on finding economic reasons for living and working beyond the Earth—reasons that do not rely on support from taxpayers. At present, we do not yet know if any of these conditions are possible. What we do know is that we will not be able to determine the answers without a space exploration and development effort that reaches beyond low-Earth orbit.

The long-term policy of sustainable space exploration and development depends on alignment with enduring national interests such as security, economic growth, scientific advancement, and a stable international environment. As new information comes to light and new experiences are gained, the United States should be prepared to adapt to new opportunities and risks. Although we are not in a Cold War-era space race, space exploration and development are urgent issues. The international environment is dynamic and influenced by competition and threats to the space capabilities on which we rely. Consequently, it is important that U.S. space activities across the civil, commercial, and national security sectors be coordinated at the highest levels and in an integrated manner to advance our holistic interests and those of our international allies.

Establishing U.S. capabilities to operate routinely in cis-lunar space and beyond will deliver strategic assets not only for ourselves, but for all like-minded nations who share our values – liberty, democracy, the rule of law, and free market economic principles. Exploration is fundamental to the American spirit, and space exploration is the modern embodiment of early frontier expeditions. It is the next step in a never-ending quest to explore and develop the unknown, while securing benefits for the American people.

Space exploration and development are not confined to one-time missions or any single destination. Rather, the effort described here is one of continually expanding human activity beyond the Earth. Close to home, the United States will encourage commercial activities to lower the public burden of maintaining and enhancing space capabilities. As the United States journeys into deep space again, it will do so with commercial and international partners as they are willing to participate and capable of participating. At the frontiers of exploration, the United States will continue to lead, as it has always done, in space. If humanity does have a future in space, it should be one in which space is the home of free people.

Appendix A: Active United States Government Programs Supporting New Era Space Development

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
ORION	Crew module that transfers astronauts from Earth to lunar orbit and back	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8
SPACE LAUNCH SYSTEM (SLS)	Heavy lift launch vehicle that sends Orion towards the Moon	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8
EXPLORATION GROUND SYSTEMS (EGS)	Ground infrastructure and services for SLS and Orion	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8
GATEWAY	Crew tended platform in lunar orbit that serves as staging point, safe haven and refueling station	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Dev. of Comm. Activities & Industry in Space, p11
HUMAN LANDING SYSTEM (HLS)	Privately owned crew module that transports astronauts from lunar orbit to the lunar surface and back	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Dev. of Comm. Activities & Industry in Space, p11 Investments in Private Space Infrastructure, p12
COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)	Privately owned cargo landers that deliver science and logistics payloads to the lunar surface	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Dev. of Comm. Activities & Industry in Space, p11
COMMERCIAL CREW PROGRAM	Privately owned crew system that transports astronauts to and from LEO	Commercialization of Low-Earth Orbit, p6 Dev. of Comm. Activities & Industry in Space, p11
COMMERCIAL CARGO PROGRAM	Privately owned cargo system that transports goods and services to and from LEO	Commercialization of Low-Earth Orbit, p6 Dev. of Comm. Activities & Industry in Space, p11
INTERNATIONAL SPACE STATION (ISS)	Continuously crewed science and exploration station in LEO	Commercialization of Low-Earth Orbit, p6
LUNAR RECONNAISSANCE ORBITER (LRO)	Robotic spacecraft in lunar orbit that maps the Moon	Returning to the Moon to Stay, p7 The Potential for Deep Space Science, p8
VOLATILES INVESTIGATING POLAR EXPLORATION ROVER (VIPER)	Robotic rover to prospect for lunar resources in permanently shadowed craters	Returning to the Moon to Stay, p7 Extending Human Presence to Mars, p8 The Potential for Deep Space Science, p8 R&D for New Technologies, p11 Support of Adv. Space Research Activities, p12
MARS 2020 & PERSEVERANCE ROVER	Mission to study the past habitability and geological history of Jezero Crater on Mars	Extending Human Presence to Mars, p8 The Potential for Deep Space Science, p8

DEPARTMENT OF COMMERCE

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
NOAA / SPACE WEATHER	Monitors and forecasts Earth's space environment	A Secure & Predictable Space Environment, p10

DEPARTMENT OF DEFENSE

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
PROJECT PELE (PARTICLE FUEL DEVELOPMENT)	Development and fielding of a deployable nuclear power reactor	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 R&D for New Technologies, p11
DEMONSTRATION ROCKET FOR AGILE CISLUNAR OPERATIONS (DRACO)	Demonstration of a nuclear thermal propulsion (NTP) system on orbit.	Extending Human Presence to Mars, p8 R&D for New Technologies, p11
UNIFIED DATA LIBRARY	Cloud-based library of space situational awareness (SSA) data	A Secure & Predictable Space Environment, p10

DEPARTMENT OF ENERGY

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
OFFICE OF NUCLEAR ENERGY	Supports a diverse set of civilian nuclear energy programs across U.S. Government including fuel development, fission reactors and radioisotope power systems	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 R&D for New Technologies, p11
OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY	Support development of hydrogen, fuel cell, and photovoltaic technologies	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 Dev. of Comm. Activities & Industry in Space, p11 R&D for New Technologies, p11
OFFICE OF SCIENCE	Develops and provides researchers with the most advanced tools of modern science	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 R&D for New Technologies, p11 Support of Adv. Space Research Activities, p12

DEPARTMENT OF INTERIOR

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
USGS (PLANTEARY GEOLOGIC MAPPING PROGRAM)	Geologic mapping of Moon and Mars	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8

DEPARTMENT OF STATE

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
ARTEMIS ACCORDS	Bilateral agreements for exploration of the Moon and eventually Mars	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 A Secure & Predictable Space Environment, p10
INTERNATIONAL GATEWAY AGREEMENTS	Multilateral agreement for international contributions to Gateway	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 A Secure & Predictable Space Environment, p10

DEPARTMENT OF TRANSPORTATION

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
FAA COMMERCIAL SPACE TRANSPORTATION RULEMAKING	Streamline requirements for regulating launch and reentry activities	A Secure & Predictable Space Environment, p10 Dev. of Comm. Activities & Industry in Space, p11
FAA GUIDANCE FOR COMMERCIAL NUCLEAR SPACE TRANSPORTATION	Public guidance for commercial launch or reentry of nuclear space systems	A Secure & Predictable Space Environment, p10 Dev. of Comm. Activities & Industry in Space, p11

DEPARTMENT OF HOMELAND SECURITY

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
RESILIENCE OF SPACE SYSTEMS	Builds programs to increase resilience of space-based systems from natural or manmade disruptions	A Secure & Predictable Space Environment, p10 Dev. of Comm. Activities & Industry in Space, p11
SPACE ISAC	Consolidates private sector space data sets to support response, mitigation and resilience initiatives	A Secure & Predictable Space Environment, p10 Dev. of Comm. Activities & Industry in Space, p11

Appendix B: Proposed United States Government Programs Supporting New Era Space Development

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
LUNAR TERRAIN VEHICLE (LTV)	Rover to transport suited astronauts and cargo on the lunar surface	Returning to the Moon to Stay, p7 The Potential for Deep Space Science, p8 Investments in Private Space Infrastructure, p12 Support of Adv. Space Research Activities, p12
HABITABLE MOBILITY PLATFORM (HMP)	Rover with pressurized cabin for crew to traverse large distances on the lunar surface	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Investments in Private Space Infrastructure, p12 Support of Adv. Space Research Activities, p12
FOUNDATION SURFACE HABITAT (FSH)	Fixed crew habitat for crew to live and operate for weeks on the lunar surface	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Investments in Private Space Infrastructure, p12
MARS SAMPLE RETURN (MSR)	Return rock and dust samples from Mars to Earth	Extending a Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Support of Adv. Space Research Activities, p12
MARS ICE MAPPER	Remote sensing mission to map near-surface water-ice on Mars	Extending a Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Support of Adv. Space Research Activities, p12
SPACE NUCLEAR PROGRAM	Small fission reactor for the lunar surface followed by nuclear propulsion demo	Returning to the Moon to Stay, p7 Extending a Human Presence to Mars, p8 The Potential for Deep Space Science, p8 Investments in Private Space Infrastructure, p12 Support of Adv. Space Research Activities, p12
COMMERCIAL LEO DEVELOPMENT	Develop both crew-tended and robotic commercial LEO platforms	The Potential for Deep Space Science, p8 Investments in Private Space Infrastructure, p12 Support of Adv. Space Research Activities, p12

DEPARTMENT OF COMMERCE

PROGRAM	DESCRIPTION	APPLICABLE "NEW ERA" SECTION
OFFICE OF SPACE COMMERCE (OPEN ARCHITECTURE DATA REPOSITORY)	A repository of commercial and allied services data to enable safe and secure space operations	A Secure & Predictable Space Environment, p10 Dev. of Comm. Activities & Industry in Space, p11

THE WHITE HOUSE