

**GLOBAL SPACE RACE: ENSURING THE UNITED
STATES REMAINS THE LEADER IN SPACE**

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE, SCIENCE,
AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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**GLOBAL SPACE RACE: ENSURING
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WEDNESDAY, SEPTEMBER 26, 2018

U.S. SENATE,
SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:28 p.m. in room SR-253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

Present: Senators Cruz [presiding], Gardner, Inhofe, Markey, and Nelson.

**OPENING STATEMENT OF HON. TED CRUZ,
U.S. SENATOR FROM TEXAS**

Senator CRUZ. This hearing is called to order.

Good afternoon. Welcome, Administrator Bridenstine.

Next week on October 1, NASA will reach a new milestone. The National Aeronautics and Space Administration will turn 60. I have to say, Mr. Administrator, you do not look a day over 55.

[Laughter.]

Senator CRUZ. The 60th anniversary of NASA's founding by Congress in 1958 provides an opportunity to not just look back at the past accomplishments but to examine how we can build upon past glory to push NASA and our national space program forward to meet new challenges facing our Nation in the 21st century.

Our country should be proud of our history in space and recognize everyone who has stepped forward to serve our nation. The United States won the space race and planted an American flag on the surface of the Moon that remains standing today.

Many of the names that have made NASA a success like Armstrong and Aldrin and Glenn have become household names that are recognizable throughout the world. Others like Katherine Johnson, Dorothy Vaughan, Mary Jackson, and all the women who served as human computers have been hidden figures in our history and are just now getting the recognition that they deserve for their legacy of brilliance and strength.

Looking forward, we have an opportunity to define a new generation, a generation that could witness American boots stepping foot on the surface of Mars and once again planting an American flag.

However, in order to achieve this goal, there are a lot of key decisions that both Congress and the administration will have to make.

I believe that this begins with extending the operation and utilization of the International Space Station beyond 2024 to 2030. American taxpayers have invested over \$100 billion in the ISS, and it is important that we maximize the return on taxpayer investment.

China is expected to have an operational space station in low earth orbit by 2022. We cannot cede low earth orbit to China or to any other nation. The United States Government must consider having a permanent human presence in low earth orbit which may require a government station after the ISS reaches the end of its useful operation. This can be accomplished without directly competing with the private sector and private space stations. We must also look to extend the presence of American astronauts beyond low earth orbit into cislunar and deep space.

The Trump administration is establishing a plan to return astronauts to the lunar surface by 2029. I share the administration's goal of returning the United States to the Moon to establish a human presence and to begin commerce.

However, it is imperative that our national space program does not get bogged down on the Moon at the expense of reaching Mars. As I have previously noted, Mars is and I believe should be the focal point of our national space program. Sending Americans to the surface of Mars and beyond will define this next generation.

I would like to thank Administrator Bridenstine for being here today. We live in interesting times, and we have the opportunity to ensure together that as the next space race begins, the United States will once again remain the leader in space.

Now I will recognize the Ranking Member of the Full Committee, Senator Nelson, to give his opening statement.

**STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA**

Senator NELSON. Naturally I would defer to the Ranking Member of the Subcommittee, but he is kind enough. As I have explained to the Administrator, another Committee commitment—the Chairman is asking for me to be there. So I will slip on out after I have made a couple of comments.

Thank you for your continuing commitment to keep NASA apolitical, and thank you for listening to the very smart and dedicated professionals. This agency is just amazing, and in many ways, it thinks of itself as a family. You are now finding out just how great a family that is.

And there is so much happening, as we just discussed. In 2017, just last year, the U.S. now has led the world in the number of commercial space launches. It is in stark contrast to just 6 years ago when the U.S. had no U.S. commercial launches. And what a difference it has made at the Cape, which hosted two-thirds of the nearly 30 U.S. launches last year. The jobs are soaring as a result of the fact that the rockets are soaring.

Now we need to make sure we have the workforce and the infrastructure to keep up that growth. I have heard from the space employees and their employers, and they tell me our education system is not keeping up with the demand—this is specifically in Florida—for the highly skilled technicians. Mr. Chairman, I look forward to

working with you to find ways to help prepare workers for the good, high-tech paying jobs of the 21st century.

As we just discussed in private, thanks for your attention to the Indian River Bridge. This is a bridge that goes from the mainland over to Merritt Island. It is a single point of failure. If you do not have a bridge, you cannot get some of the payloads over to NASA and to the Air Force for that matter. The deterioration of this bridge jeopardizes our access to space. And so we put in the Defense Authorization Act a provision to get the Department of Defense's skin in the game.

NASA owns the bridge. So NASA is going to need to continue to lead the way as the Kennedy Space Director Bob Cabana has done so ably. And we have talked with our colleagues on Appropriations to understand the issue. So they will be looking for your plan, NASA's plan, to replace the bridge.

The 2017 authorization bill required NASA to define and deliver to Congress a step-by-step plan for reaching Mars, which was delivered to us last week, but it was supposed to be delivered in 2017. The road map builds up to a human landing on the Moon no later than the end of the decade—I am interpreting that to be 2029—then references a human mission to orbit or to fly by Mars sometime in the 2030s.

You heard what the Chairman said, and the Chairman and I are of one accord because where we are going is where we should be going. What is it going to take us to get to Mars, on the surface of Mars, in the decade of the 2030s? Flat budgets certainly are not going to cut it, and we cannot afford to sacrifice NASA's other critical priorities in so many other areas, including science and technology and aeronautics.

The Chairman, the Ranking Member, and I are all in accord. We cannot afford to walk away from the International Space Station in 2024 when NASA has made it very clear that we are going to have enduring needs for low earth orbit. And so all of us are looking forward to continuing to work with you.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Nelson.

Now I will recognize the Ranking Member of the Subcommittee, Senator Markey.

**STATEMENT OF HON. EDWARD MARKEY,
U.S. SENATOR FROM MASSACHUSETTS**

Senator MARKEY. Thank you, Mr. Chairman, and thank you for having this very important hearing.

When President Kennedy addressed Rice University in 1962, he said “the growth of our science in education will be enriched by new knowledge of our universe and environment by new techniques of learning and mapping and observation.” This was true then and it is even truer now.

The discoveries from NASA's Science and Technology Directorate not only inform our understanding of space but also often improve our lives here on Earth, as we learned during the recent hearing on the journey to Mars.

That is why I am strongly concerned by some of the proposals contained in the President's budget request for 2019 which

prioritizes lunar exploration at the expense of other critical programs such as earth science and astrophysics. The President's request aimed to eliminate the Office of Education, which develops the next generation of NASA scientists. That to me is a mistake. It would merge the Science and Technology Directorate into Exploration Research further putting necessary technology development below exploration. And within our exploration missions, the administration is focusing on going back to the Moon rather than achieving the ambitious goal of going to Mars and beyond.

I believe that only a balanced portfolio of exploration, research, and technology will actually guide us boldly into a promising future, not just keep our eyes in the past.

Mr. Bridenstine, you were asked by me at your last visit here about the rampant fear amongst government scientists that they could be punished for speaking publicly about their work on climate science with so many people working within the administration who deny basic climate facts. We are relying on NASA to recruit the brightest of all scientists to produce the best possible science, including research that looks into our affect on the globally changing climate. I look forward to hearing what steps you have taken to protect scientists and continue to promote climate science. At your testimony before the Appropriations Committee, I heard very positive comments that you made on this subject, and I am looking forward to further exploring it here today.

I hope to continue to see NASA prioritize the earth science and technology development that could help us all better understand the threats posed by climate change emission. It is particularly well suited to carry out with its understanding of climates on other planets and its unique view of our own. We will need all the brilliant minds at NASA to continue studying climate change, researching other worlds, and developing new technologies that will continue to bring us into the future and humans to other planets.

So I thank you for testifying today, and I thank you, Mr. Chairman, for this very, very timely hearing.

**STATEMENT OF HON. JIM INHOFE,
U.S. SENATOR FROM OKLAHOMA**

Senator INHOFE. Mr. Chairman, just one quick comment.

First of all, I am not on this Subcommittee, but I wanted to be here because I am so proud of what Administrator Bridenstine is doing. I know you are going to keep focused on our mission as opposed to some of the other agendas that are floating around here.

But I am chairing another hearing. I want to hear your opening statement. I am proud of you and looking forward to great things.

Senator CRUZ. We welcome Senator Inhofe to the Subcommittee.

And I would note of our Ranking Member, I am grateful for his quoting JFK at Rice. I just wish he would fulfill his potential to this Committee and do the full Boston accent when you are quoting JFK.

[Laughter.]

Senator CRUZ. And if I could be so presumptuous as to speak on behalf of your constituents as well in encouraging—

Senator MARKEY. I try when I am speaking about the future to ensure that the past is properly represented in this hearing and in

all other places that I go to. My mother wanted me to sound like this.

[Laughter.]

Senator MARKEY. Unfortunately, down the park, I had to drop this accent and sound more like the other boys down at Debber Park in Waltham. We all grew up bilingual in Boston in the 1960s.

[Laughter.]

Senator MARKEY. And I still have both accents. And I can speak it because of the impact he had on us, especially the speech at Rice University. It was something that we almost all memorized, and we are challenged by him to be here. And that is why Houston and Boston are linked historically in this mission that we are trying to advance here today.

Senator CRUZ. Indeed, although I still have not forgiven the Celtics for beating the Rockets in 1986.

Senator MARKEY. And in 1981.

[Laughter.]

Senator CRUZ. Yes. I knew that was coming.

Senator MARKEY. You know, the past in Boston is never in the past. The past is always today as well.

So you have the space program, and we have two NBA titles, which I am not sure is a good division.

[Laughter.]

Senator CRUZ. Well, I now have the opportunity to introduce our witness. Mr. Jim Bridenstine is the current Administrator of NASA. In his role at NASA, Administrator Bridenstine provides clarity to the agency's goals and aligns the strategic and policy direction of NASA with the interests and requirements of the agency's stakeholders and constituent groups.

Prior to joining NASA, he was elected and represented Oklahoma's first congressional district in the United States House of Representatives—

Senator INHOFE. That is my old seat.

Senator CRUZ.—Senator Inhofe's old seat, where he served on the House Armed Services Committee and the House Science, Space, and Technology Committee.

Before joining Congress, Administrator Bridenstine served as the Executive Director of the Tulsa Air and Space Museum and Planetarium.

Administrator Bridenstine also served honorably in the United States Navy as a naval fighter pilot where he flew combat missions in Iraq and Afghanistan.

Administrator Bridenstine completed a triple major in Texas at Rice University and earned his MBA at Cornell University.

The Administrator is a dear friend of mine, and I will say since he has been confirmed, every time I have the chance to interact with employees at NASA, with scientists, with engineers, just my flight from Houston to D.C. on Monday, I sat next to two NASA engineers. And I ask everyone the same question, which is how is Jim doing, what kind of job he is doing. And without exception, every person I have asked has given glowing reports. He is terrific. He is passionate. He cares about the agency, and we are moving in the right direction.

So with that, Administrator Bridenstine, you may give your opening statement.

**STATEMENT OF HON. JAMES F. BRIDENSTINE,
ADMINISTRATOR, NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION**

Mr. BRIDENSTINE. Thank you, Chairman, and thank you Ranking Member.

I am going to take a little bit of risk here, but since my alma mater has been mentioned a number of times, I would like to bring up another critical point that our President, John F. Kennedy, asked in that very important address at Rice University. And it is a question all of us should be asking when we think about NASA. It is a question that is very profound. And the question was this. He asked, "Why does Rice play Texas?" And the answer was of course—and the speech was in 1962, one of the greatest orations in the history of the United States of America. The answer of course was because in 1965 Rice was going to beat Texas. And of course, again in 1994, when I was a sophomore—actually 1995 when I was a sophomore, we beat Texas again. So the answer for the President is we play Texas because we are racking up wins. That is why we play Texas.

[Laughter.]

Mr. BRIDENSTINE. Well, Mr. Chairman and members of the Subcommittee, I am very pleased to be before you here today.

NASA is proud to be at the forefront of a global effort to advance humanity's future in space and scientific discovery, leading the world while capitalizing on our nation's great capacity for exploration and innovation.

Pursuant to the National Space Policy Directive 1 and consistent with the NASA Transition Authorization Act of 2017, NASA is pursuing, "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."

We will transition the ISS, returning humans to the surface of the Moon and lunar orbit where we will build the systems, deep space infrastructure, and operational capabilities to expand human presence beyond the Earth-Moon system.

The National Space Exploration Campaign builds on 18 years of Americans and our international partners living and working continuously on the International Space Station. It leverages the advances made in commercial launch vehicle capabilities, robotics, and other technologies and accelerates in the next few years with the launch of the Orion crew capsule and the Space Launch System, which will expand human exploration to cislunar space and to the surface of the Moon.

A key component of establishing the first sustainable American presence and infrastructure on and around the Moon is the Gateway, a spacecraft assembled in cislunar space that will be used as a staging point for missions to the lunar surface and to deep space destinations. A strong focus on robotic activities and infrastructure will enable ongoing investigations and autonomous operations between crew visits to the Gateway.

NASA will develop an open architecture that meets national objectives. We will draw upon a variety of innovative partnerships with U.S. commercial industry, other government agencies, academia, and international partners. So when I say open architecture, I am talking about the idea that commercial companies could build landers or they could build tugs that would actually integrate with the Gateway in orbit around the Moon. So the way we do docking, the way we share power is all going to be part of the open architecture that the United States of America will lead.

The exploration campaign is designed to enable early successes, relying on seamless collaboration across the agency, including deep space exploration systems, exploration technology, low earth orbit and spaceflight operations, and elements of science and the rapidly advancing capabilities of our commercial partners. NASA will expand public-private partnerships to develop and demonstrate technologies and capabilities to enable new commercial space products and services.

NASA's planetary, astrophysics, earth science, and heliophysics missions will continue to advance our understanding and make exciting new discoveries to preserve American leadership in science making civilization-changing discoveries and improving our understanding of critical issues such as space weather to preserve American assets in space and improve our lives here on Earth.

NASA will continue to sustain and develop new partnerships to explore transformative technologies and approaches. Upcoming early stage innovation activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and materials. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and develop exciting new capabilities.

NASA is leading an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and bring back to Earth new knowledge and new opportunities. The agency will return astronauts to the Moon and encourage the creation of a thriving commercial space economy in LEO and beyond. We will monitor the Earth and the Sun, explore the planets of our solar system, observe the universe beyond, and make aviation safer, more efficient, and more environmentally friendly.

We appreciate this Subcommittee's continued support, and I would be pleased to respond to any questions.

[The prepared statement of Mr. Bridenstine follows:]

PREPARED STATEMENT OF HON. JAMES F. BRIDENSTINE, ADMINISTRATOR,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and Members of the Subcommittee, I am very pleased to appear before you today. NASA is proud to be at the forefront of a global effort to advance humanity's future in space, leading the world while expanding on our Nation's great capacity for exploration and innovation. Pursuant to Space Policy Directive-1 (and consistent with the NASA Transition Authorization Act of 2017), NASA is pursuing "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." We are working on a sustainable campaign of exploration, transitioning the International Space Station (ISS), returning humans to the surface of the Moon and lunar orbit, where we will build the sys-

tems, deep space infrastructure, and operational capabilities to expand human presence beyond the Earth-Moon system, eventually embarking on human missions to Mars and other destinations.

Exploration Campaign

The National Space Exploration Campaign builds on 18 years of Americans and our international partners living and working continuously on the ISS. It leverages the advances made in commercial launch vehicle capabilities, robotics, and other technologies, and accelerates in the next few years with the launch of the Orion capsule and Space Launch System (SLS) rocket which will expand human exploration to cislunar space and the surface of the Moon.

A key component of establishing the first permanent, American presence and infrastructure on and around the Moon is the Gateway, a spacecraft assembled in cislunar space that will be used as a staging point for missions to the lunar surface and to deep space destinations. The Gateway will not be continuously occupied like the ISS. NASA currently envisions crew visits approximately once per year, so a strong focus is placed on robotic activities and infrastructure to foster ongoing investigations and operations that can operate autonomously between crew visits. Gateway in-space assembly starts with the launch of the power and propulsion element (PPE) no later than 2022 aboard a commercial rocket. Gateway ground testing, risk reduction, and development activities are already underway at NASA centers across the United States, including facilities in Ohio, Texas, Florida, Virginia, and Alabama, as well as in facilities of private sector partners in those states as well as in Colorado and Nevada. Following the successful in-space demonstration of the PPE and the delivery of the first pressurized Gateway modules, U.S. astronauts will be visiting before the end of 2024.

As part of the Campaign, we will also begin sending increasingly capable robotic missions to the lunar surface in the next two years. Developed by U.S. commercial companies, these spacecraft will conduct scientific investigations, characterize resources, and provide lunar landing services to customers from America and around the world. Ultimately, these efforts will culminate in the safe landing of U.S. astronauts on the Moon before the end of the 2020s.

We will also continue to execute sophisticated robotic missions to Mars while we work to develop and demonstrate the deep space capabilities required to safely send a human crew to the Red Planet.

Activities across these domains are closely related and mutually supportive; for example, NASA's drive to conduct robotic and human exploration of the Moon informs the research and technology development we will conduct on the ISS and potential future orbital platforms, as well as the development of technologies needed for future Mars missions. Likewise, current and future robotic missions will provide vital science, reconnaissance, and technology demonstrations in support of future human exploration, in addition to their science objectives. NASA is actively working now to support sustainable exploration and development over the coming decades in all three domains.

The Exploration Campaign has five strategic goals:

1. Transition U.S. human spaceflight in LEO to commercial operations that support NASA and the needs of an emerging private sector market.
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 the capabilities required for human missions to Mars and other destinations.

NASA will act as architect, mission leader, and in several key areas, systems integrator, defining an open architecture that meets National objectives. The Exploration Campaign will draw upon a variety of innovative partnerships with U.S. commercial industry, other Government agencies, academia, and international partners. We have designed the Exploration Campaign to enable early successes, relying on seamless collaboration across the Agency, including Deep Space Exploration Systems, Exploration Technology, LEO and Spaceflight Operations, and elements of Science, and the rapidly advancing capabilities of our commercial partners. I'll now describe our plans in each major domain of the Campaign—Earth Orbit, the Moon, and Mars—in more detail.

Transitioning LEO

The ISS will continue to serve as a core long-duration human spaceflight asset through at least 2024—which will mark nearly 25 years of continuous human occupancy. Currently, NASA is leveraging the ISS to learn how to keep crews healthy and productive on deep space missions, and as a testbed to develop technologies to support those missions. The ISS is an experiential testing ground that enables discovery and development of advanced robotics, communications, medicine, agriculture, and environmental science. ISS also provides an example of international collaboration on large space projects. ISS can also enable the transition to commercial companies' use of LEO. NASA recently awarded 12 study contracts to industry to investigate the best way to use the ISS to enable commercial industry to take a lead role in LEO. The portfolio of selected studies will include specific industry concepts detailing business plans and the viability of habitable platforms, using Station or separate free-flying structures.

Maintaining the ISS and future orbital platforms requires a fleet of vehicles to sustain a constant supply line of both crew and cargo. Under the original Commercial Resupply Services (CRS) contracts, our two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK (now Northrop Grumman), are providing cargo deliveries to the ISS. Under the new CRS-2 contracts, SpaceX, Northrop Grumman, and Sierra Nevada Corporation will deliver critical science, research, and technology demonstrations to the ISS over five years from 2020 through 2024. Working with our commercial crew partners, SpaceX and the Boeing Company, NASA plans to return crew launch capability to American soil in 2019.

Under the auspices of the ISS National Laboratory, managed by the Center for the Advancement of Science In Space (CASIS), NASA and CASIS continue to expand research on the ISS sponsored by pharmaceutical, technology, consumer product, and other industries, as well as by other Government agencies, such as the National Institutes of Health and the National Science Foundation. Through CASIS' efforts, the ISS National Lab has reached full capacity for allocated crew time and upmass and downmass. NASA also works with commercial companies, such as NanoRacks, to support commercial activity on the ISS.

NASA intends to transition from the current Government-dominated model of human space activities in LEO to a model where Government is only one customer for commercial services. Starting in 2018, the Agency will increase the breadth and depth of commercial and international LEO activities. NASA will expand partnerships in LEO to include new companies and new nations, including working with commercial partners to support new international astronaut visits. Based on inputs from current ISS partners, commercial and other stakeholders, NASA will shape the plan for the transition of LEO activities from direct Government funding to commercial services and partnerships, with new, independent commercial platforms or a non-NASA operating model for some form or elements of the ISS by 2025. In addition, NASA will expand public-private partnerships to develop and demonstrate technologies and capabilities to enable new commercial space products and services.

Lunar Exploration

NASA is building a launch and crew system—the Orion spacecraft, the heavy-lift SLS launch vehicle, and the supporting Exploration Ground Systems (EGS)—to support the Exploration Campaign. The Orion crew vehicle will carry up to four humans to deep space for up to 21 days. The Orion will also be able to transport and dock co-manifested modules to Gateway, and provide key initial life-support and abort capabilities. The SLS Block 1 cargo variant will be capable of delivering Orion to cislunar space in the early 2020s, and the Block 1B SLS will be capable of delivering 8–10 metric tons co-manifested with Orion in the mid-to late-2020s. The first SLS/Orion mission will be the uncrewed Exploration Mission-1 (EM-1), to be launched to lunar orbit in FY 2020, followed by the first crewed SLS/Orion mission, EM-2, no later than 2023. These SLS/Orion missions will demonstrate the capability to operate safely and productively around the Moon. These are the early steps on a journey that leads American astronauts into deep space, sustainably and permanently.

SLS Core Stage integration and outfitting (including installation of the four RS-25 main engines developed from the Space Shuttle) has continued at Michoud Assembly Facility. EM-1 flight hardware is being delivered to the Kennedy Space Center (KSC). SLS has continued a series of EM-1 Design Certification Reviews, will conduct the Critical Design Review (CDR) for EM-2, and begin fabrication of components for EM-3 and beyond. For EM-1, the Orion European Service Module is scheduled to be delivered soon to the Operations and Checkout Building at KSC for integration with the Crew Module. NASA is accelerating the Ascent Abort-2 test (AA-2) into 2019, ahead of EM-1. Structural work is already underway on Orion

EM-2 flight hardware production. Orion has continued qualification testing of systems for EM-2. This year, EGS will complete the system verification and validation phase and begin the operations and integration phase in preparation for multi-element verification and validation for the Mobile Launcher, Pad, and Vehicle Assembly Building.

NASA will also begin to build the in-space infrastructure for long-term exploration and development of the Moon by delivering to lunar orbit a power and propulsion element (PPE), planned to be launched in 2022 on a commercial rocket, as the foundation of the Gateway. NASA released the PPE final Broad Agency Announcement (BAA) in September and proposals are due in November. This BAA is designed to leverage the commercial communication industry's extensive experience in building and operating spacecraft. The Gateway is envisioned to be a spacecraft operating in the vicinity of the Moon that demonstrates crewed and uncrewed operations in deep space. It will be incrementally built in place using SLS, the Orion crew vehicle, and commercial launch vehicles. The Gateway will be assembled in lunar orbit where it can be used as a staging point for missions to the lunar surface and destinations in deep space, providing a flexible human exploration architecture depending on mission needs. Although there are various concepts for its configuration, current analysis suggests the initial functionality will include four main capabilities: PPE; habitation; airlock to enable science and EVA; and logistics for cargo delivery, science utilization, exploration technology demonstrations, and potential commercial utilization. With the initial habitation capabilities delivered to cislunar space, crews of four—launched on Orion—will visit the Gateway on missions initially lasting 30 days and up to 90 days as new modules are added to complete Gateway's full capabilities.

Gateway will enable system and operational demonstrations, scientific exploration, biological and biomedical science, and will serve as an eventual aggregation and departure point for crewed missions to the lunar surface and other deep space destinations. The Gateway will serve as a critical platform to conduct biological and biomedical studies that require a beyond-LEO space environment to study the response of biology (human and non-human organisms) to this new environment. A key science-enabling feature of this spacecraft is exposure of organisms to the deep space radiation environment for radiation and combined radiation/microgravity studies. The Gateway will also serve as a platform to mature necessary short- and long-duration deep space exploration capabilities in the 2020s, including highly reliable and dormancy-tolerant environmental control and life support systems; logistics reduction capabilities; advanced in-space propulsion; automated rendezvous and docking; radiation monitoring and mitigation capabilities; and integrated human-robotic mission operations, to name a few.

NASA has established the Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate and is leveraging the Agency's extensive lunar science experience and data for lunar exploration. We are jump-starting commercial partnerships, innovative approaches for building and launching sophisticated next-generation science instruments, and the development of small rovers that will reach the Moon's surface via commercial landers. The Agency is integrating science and human exploration goals, including the eventual return of humans to the Moon. Just this past year, scientists used data from NASA's Lunar Reconnaissance Orbiter to identify areas in lunar craters that are cold enough to have frost present on the surface—ice that could provide crucial resources for exploration while also containing valuable information about the chemical makeup of the early solar system.

NASA is supporting the development of commercial lunar exploration capabilities leading to a human lunar landing. The Advanced Cislunar and Surface Capabilities (ACSC) program in the Human Exploration and Operations Mission Directorate will focus on engaging U.S. industry partners using innovative approaches to combine lunar robotics, a cislunar presence, and lunar landing capabilities building up to a human-rated lander. In 2019, ACSC and LDEP will support initial risk reduction activities by incorporating results from the following.

- The Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) initiative is encouraging the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities.
- NASA issued a request for proposals (RFP) for Commercial Lunar Payload Services (CLPS) on September 6, 2018, encouraging the U.S. commercial space industry to introduce new technologies to deliver payloads to the Moon. NASA intends to award multiple contracts for these services through the next decade, with contract missions to the lunar surface expected to begin as early as 2019, and with a company's first delivery no later than Dec. 31, 2021.

- NASA is also working on the second phase of the Next Space Technologies for Exploration Partnerships (NextSTEP), an effort to stimulate deep-space capability development across the aerospace industry. Through NextSTEP, the Agency intends to seek proposals from industry in support of design analysis, technology maturation, system development and integration, and spaceflight demonstrations for human-class lunar landers. This will address the development of medium-to large-scale lunar lander capabilities that have extensibility to reusable, human-class landers to a wide range of destinations on the lunar surface.

Ultimately, the Moon will also serve as a stepping-stone, a training ground, and a platform to strengthen commercial and international partnerships and prepare for future human missions to Mars and other destinations.

NASA will advance robotic access to Mars in preparation for human exploration. The Agency will:

- Continue the search for life with a Mars rover in 2020;
- Demonstrate technology to produce oxygen from Mars resources, critical for future human Mars missions;
- Begin planning a first-ever sample-return Mars mission;
- Prioritize and guide investments and partnerships in long-pole technology areas and resource characterization needed for deep-space exploration; and
- Develop standards for human long-duration deep space transportation vehicles.

Exploration Technology

Critical to the Exploration Campaign, NASA will conduct research and promote technology development to address needs for human and robotic space exploration and to foster commercial expansion in LEO, cislunar space, and beyond. NASA's Technology research drives exploration by spanning the Technology Readiness Level spectrum, including investments in early-stage concepts and prototypes. Exploration Research and Technology key areas of focus will include:

- Advanced environmental control and life support systems;
- In-Situ Resource Utilization (ISRU);
- Nuclear and solar power and propulsion technologies for exploration;
- Advanced communications, navigation, and avionics;
- In-space manufacturing and on-orbit assembly;
- Advanced materials;
- Entry, Descent, and Landing;
- Autonomous operations; and
- Research to enable humans to safely and effectively operate in various space environments.

NASA continues to partner with researchers across academia, industry, and within the Agency to explore transformative technologies and approaches. Upcoming early-stage innovation activities will investigate areas such as breakthrough propulsion, challenges in deep space human habitation, space-optimized energy systems, radiation protection, and materials. These areas are part of a comprehensive approach to efficiently support innovative discovery, progress toward important goals, and development of exciting new capabilities.

In August, NASA selected 10 proposals from six U.S. companies, with a combined award value of approximately \$44 million, to develop commercial space capabilities that benefit future NASA exploration missions in new public-private partnerships, including lunar lander and deep space rocket engine technologies. While these "Tipping Point" partnership selections will enable NASA's future science and human exploration missions, these awards will also grow the economy and strengthen the Nation's economic competitiveness.

This past spring, NASA also selected 10 companies to conduct studies and advance ISRU technologies to collect, process, and use space-based resources for missions to the Moon and Mars. ISRU could increase safety and affordability of future human spaceflight missions by limiting the need to launch supplies such as oxygen and water from Earth. In the area of Flight Opportunities, suborbital flight providers are now on the verge of a significant leap forward, and payloads are beginning to fly from multiple providers. Given this success, NASA will shift our focus to funding more payload flights. To date, Flight Opportunities has enabled 122 flights of 93 payloads. There are an additional 62 payloads awaiting flight. Later this year, we look forward to the launch of the Green Propellant Infusion Mission

and the Deep Space Atomic Clock on the U.S. Air Force's Space Technology Mission-2 on a SpaceX Falcon Heavy booster.

Planetary Science

NASA's Planetary Science program develops and operates missions that explore our solar system and search for life elsewhere, helping to answer fundamental questions about our place in the universe. NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander launched on May 5 of this year, and will land on Mars on November 26, joining a series of NASA rovers, landers, and orbiters already at the Red Planet. InSight's advanced payload will provide unique information on the interior structure of Mars, providing glimpses into the processes that shaped the rocky planets of the inner solar system. The Agency is also working on the Mars 2020 rover and planning for a potential Mars Sample Return mission incorporating commercial and international partnerships—a top priority identified by the scientific community in the most recent National Academy of Sciences (NAS) planetary decadal survey. In addition, we received radio signals indicating that the first-ever CubeSats headed to deep space are alive and well. Launched along with InSight, Mars Cube One, or MarCO, is a pair of briefcase-sized spacecraft that will test out miniature spacecraft technology along the way to Mars.

On December 3, 2018, NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission will arrive at the asteroid Bennu, providing unique data that will shed light on the early history of the solar system. OSIRIS-REx measurements of the composition of the potentially hazardous Bennu will also inform the design of future missions to mitigate asteroid impacts on Earth, an effort aligned with and supporting NASA's new Planetary Defense program. On January 1, 2019, the New Horizons spacecraft will fly by a Kuiper Belt Object, returning new information about the unusual bodies that occupy this distant part of our solar system. During 2018, NASA has continued development of the cutting-edge Europa Clipper mission to fly by Jupiter's ocean moon, and will announce the next scientifically and technologically innovative New Frontiers mission: either a comet sample return or a drone to explore Saturn's largest moon, Titan.

Astrophysics

NASA's Astrophysics program investigates the origin and evolution of the universe and the formation of planetary systems. It examines how environments hospitable for life develop, and contributes to the search for the signature of life on other worlds. The program operates the Hubble, Chandra, Spitzer, Fermi, Kepler, Swift, Nuclear Spectroscopic Telescope Array (NuSTAR), and the Transiting Exoplanet Survey Satellite space telescopes, flies the airborne Stratospheric Observatory for Infrared Astronomy (SOFIA), and conducts balloon and suborbital rocket campaigns.

NASA's impressive observatories will be joined by the James Webb Space Telescope, which will detect the first stars and galaxies that formed after the big bang, and will take the next giant leap in characterizing planets orbiting other stars and searching for Earth-like planets. Successfully implementing the Webb mission is a high priority and critical to maintaining national leadership in the space sciences.

Webb is in the final stages of its development. All of its hardware has been fabricated, and the flight hardware and software are undergoing the last major steps of its integration and testing (I&T) phase. However, early this year, NASA recognized that it would take longer to complete the Spacecraft element I&T than previously estimated. NASA formed an Independent Review Board (IRB) chaired by A. Thomas Young, a distinguished leader of the aerospace community. After considering the IRB's recommendations, NASA has established March 30, 2021, as Webb's new launch date, and the estimated development cost, including launch and commissioning, has risen to slightly over \$8.8 billion, up from the nearly \$8 billion development-cost estimate established in 2011. We have not yet determined what impacts this cost overrun will have on other NASA programs and projects, but our plan will be informed by the priorities established through the National Academy's decadal surveys. We look forward to providing our funding plan for successful completion of Webb to this Committee as part of the FY 2020 budget request.

Two new astrophysics missions were launched to the ISS in 2017—the Neutron Star Interior Composition Explorer (NICER) in June and the Cosmic Ray Energetics and Mass (CREAM) experiment in August of that year. NICER is the first NASA mission dedicated to studying pulsars—the densest observable objects in the universe, and CREAM monitors the cosmic rays that constantly shower the Earth. The Transiting Exoplanet Survey Satellite (TESS), launched on April 18, 2018, is

NASA's next planet-hunting mission, searching for planets orbiting nearby stars. In August 2017, NASA selected six astrophysics Explorer Program proposals for concept studies. The proposed missions will collect unprecedented measurements of gamma-ray and X-ray emissions from galaxy clusters and neutron star systems, infrared emissions from galaxies in the early universe, and atmospheres of exoplanets. In January 2019, NASA will select at least two of these proposals for flight.

Heliophysics

NASA's Heliophysics program studies how the Sun affects the Earth and objects around it, how it influences other planets in the solar system, and how our star affects the very nature of space itself. Improved understanding of the Sun and information about the space weather phenomena it produces is used to provide warnings and better protect lives and essential—but vulnerable—systems on Earth, as well as to safeguard astronauts, satellites, and robotic missions traveling through the solar system. The program includes operation of, and analysis of data from, the Solar Dynamics Observatory (SDO), the joint European Space Agency (ESA)-NASA Solar and Heliospheric Observatory (SOHO), and the Solar Terrestrial Relations Observatory (STEREO). These assets will be joined by future assets such as the ESA-NASA Solar Orbiter Collaboration (SOC), currently in development. Together, they constantly monitor the Sun, revealing coronal mass ejections and releases of solar energetic particles, while also advancing scientific understanding of our star's fundamental dynamics. Closer to Earth, the Magnetospheric Multiscale (MMS) mission uses four small spacecraft flying in formation to gather information on Earth's magnetic environment, changing our understanding of how that environment protects our planet.

The Global-scale Observations of the Limb and Disk (GOLD) instrument was launched aboard a commercial communications satellite in January 2018, and the Ionospheric Connection Explorer (ICON) spacecraft is slated for launch later this year. Together, they will provide the most comprehensive observations of the ionosphere—a region of charged particles in Earth's upper atmosphere—ever achieved. The Geospace Dynamics Constellation (GDC) mission, which is currently nearing the end of its definition phase, will provide key understanding of the interaction of various regions in geospace where space weather has its greatest impact on space assets. The Space Environment Testbed 1 mission, a technology demonstration mission developed in partnership with the United States Air Force, is scheduled for launch in 2018, and three heliophysics CubeSats are being prepared for launch as part of NASA's CubeSat Launch Initiative. Perhaps most exciting is the recent launch of the Parker Solar Probe, which began its journey last month, and will make its first close fly-by of the Sun in November. This historic mission will be the first to travel through the Sun's atmosphere, providing humanity with the closest-ever observations of a star.

In July 2017, NASA selected five heliophysics Explorer Program proposals and three missions of opportunity for concept studies. The proposed missions will investigate fundamental space physics energization and coupling phenomena in the Sun's extended atmosphere and in Earth's magnetosphere, and develop observation techniques directly applicable to space weather capabilities. In December, NASA will select at least one mission of opportunity and in March 2019, will select at least two explorer proposals for flight.

These assets join other missions in the Heliophysics Great Observatory, working in concert to provide the Nation with critical data to protect and improve life on Earth.

Earth Science

NASA's Earth Science program makes revolutionary observations of our planet's land, oceans, and atmosphere from the vantage point of space; combines measurements of many different quantities to understand and accurately model the Earth's complex system of interacting processes; and provides practical benefits by transforming the measurements and understanding into focused information products that are used broadly to improve the quality of life for all humans.

In August and September 2017, data products from NASA Earth-observing research satellites were used to support real-time decision making, response, and recovery planning efforts by the Federal Emergency Management Agency, other operational agencies, and first responders on the ground in the affected areas during the catastrophic landfalls of hurricanes Harvey, Irma, and Maria.

NASA's Earth Science program is also pioneering innovative partnerships and mission strategies to achieve science goals rapidly and cost-effectively, including pilot data buys and evaluations of data products from commercial, on-orbit small-satellite constellations. The low-cost, competitively-selected ECOSystem Spaceborne

Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument to measure agricultural water use in the United States and vegetation stress around the globe, and to identify drought warning conditions, was launched to the ISS on June 29, 2018. Two major competitively selected payloads—Tropospheric Emissions: Monitoring of Pollution (TEMPO) to measure North American air quality, and Geostationary Carbon Cycle Observatory (GeoCarb) to measure natural carbon flux processes in the western hemisphere—are being developed for flight as hosted payloads on commercial communications satellites.

Launching in 2018, two important NAS-decadal-survey-recommended missions will expand the long-term collection of key Earth observations. Making precise measurements of gravity from two spacecraft, the GRACE Follow-On mission (a partnership with German research and space agencies, which launched on May 22, 2018), will provide global information on ice sheet and oceanic mass balances, underground water storage changes in aquifers, and regional drought conditions. The Ice, Cloud and land Elevation Satellite-2 (ICESat-2) was launched on Sept. 15 to map and monitor land ice topography and glacier flow, sea ice thickness, and the heights of the vegetation canopy at low-and mid-latitudes across the globe. NASA remains on track to launch Landsat-9 in December 2020.

NASA's Joint Agency Satellite Program brings NASA's best practices to bear to support our interagency customer NOAA in the development of critical weather satellites for the Nation. The Joint Polar Satellite System-1 (JPSS-1, now NOAA-20) successfully launched in November 2017, and Geostationary Operational Environmental Satellite-S (GOES-S, now GOES-17) successfully launched in March 2018.

Aeronautics Research

NASA's work has always strengthened our security and the economy, and our ongoing research and testing of new aeronautics technologies is critical in these areas. This work will help us lead the world in a global aviation economy with increasing benefits worldwide. X-planes, Urban Air Mobility, commercial supersonic flight, unmanned aviation systems, advanced hypersonics technologies, and the next generation of aircraft are critical focuses of NASA's research. NASA's Aeronautics Research program advances U.S. global leadership by developing and transferring key enabling technologies to make aviation safer, more efficient, and more environmentally friendly. The Agency is working on critical concepts and technologies required to support continued global leadership in civil aviation.

NASA recently awarded a competitive contract for detailed aircraft design, build, and validation of the Low-Boom Flight Demonstrator (Lbfd) X-plane, now designated the X-59 QueSST. The X-59 will demonstrate quiet overland supersonic flight and enable U.S. industry to open a new market and is on track for first flight by FY 2021. Data generated from flights of this demonstrator will feed directly into national and international regulatory decision-making processes and timelines, enabling a rule change to allow civil supersonic flight over land. NASA will also continue to advance new subsonic aircraft technologies that will dramatically reduce fuel consumption, noise, and emissions through a combination of numerical analyses, ground tests, and flight experiments.

NASA's Aeronautics work includes developing revolutionary tools and technologies such as hybrid and all-electric aircraft, autonomy, advanced composite materials and structures, data mining, verification and validation of complex systems, and revolutionary vertical-lift vehicles. This work enables further advances for transformative vehicle and propulsion concepts that will address a broad array of our aviation industry's needs. For example, in partnership with industry, NASA is delivering a variety of computational tools and guidance that will significantly reduce the time needed to develop and certify new composite structures for aerospace applications.

NASA is advancing the state of the art in key technologies needed to realize practical larger-scale hybrid electric propulsion systems for the future. We will be flight-testing an advanced configuration of the X-57 Maxwell aircraft, a general-aviation-scale aircraft to test highly integrated distributed electric propulsion technology. This demonstration will address the integration of electrical and power distribution components critical to development of standards and certification methodologies required to enable widespread use of electric and hybrid electric propulsion in civil aviation, and eventually in commercial airline fleets.

NASA is demonstrating new air traffic management (ATM) tools that integrate aircraft arrival, departure, and airport surface operations to reduce flight delays and increase air traffic capacity and safety, supporting realization of the Federal Aviation Administration's (FAA's) full vision for the Next Generation Air Transportation System (NextGen). Even with limited operational trials at the Charlotte Douglas International Airport, technologies being developed by the ATM Technology Dem-

onstration-2 Project are already showing significant savings in fuel burns and delays during taxi operations.

NASA is advancing the realization of routine access of Unmanned Aircraft Systems (UAS) into the National Airspace System for civil use by completing flight testing of detect and avoid (DAA) and communications technologies, and providing the data to standards development committees and the FAA to support UAS rule making. Additionally, NASA will help support safe, low-altitude operations of small UAS through development and demonstration of the UAS Traffic Management concept (UTM) in high-density urban areas. This comprehensive demonstration of the UTM concept in the most challenging operational environment will set the stage for transition to and implementation by the FAA and industry.

NASA's hypersonic fundamental research will enable development of tools and methods to more efficiently design future hypersonic vehicles.

Today, we stand on the cusp of the next era in aviation. Recent technology advances are coming together to enable breakthroughs in the speed and efficiency of the transport aircraft that are the backbone of the aviation system. Other breakthroughs will enable new markets for smaller aircraft, from UAS that serve search and rescue, agricultural, and commercial applications to the potential for new modes of personal transport. Global competition is fierce in all of these markets. NASA's development of aircraft, UTM and Urban Air Mobility technologies will accelerate the U.S. competitive posture in the global race to achieve leadership in emerging air mobility markets. U.S. companies will build on these advances and introduce new commercial products ranging from small UAVs to air taxis to large commercial aircraft. These innovations will support new jobs, new opportunities, and new ways for the U.S. to lead the world in technology and innovation.

Conclusion

NASA 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. The Agency will return astronauts to the Moon and encourage the creation of a thriving commercial space economy in LEO and beyond; monitor the Sun and Earth, explore the planets of our solar system, and observe the universe beyond; and make aviation safer, more efficient, and more environmentally friendly. We appreciate the Subcommittee's continued support, and I would be pleased to respond to your questions.

Senator CRUZ. Thank you, Administrator. Thank you for your good work.

In your opinion, what are the top priorities for NASA that Congress should look to address in a new NASA reauthorization?

Mr. BRIDENSTINE. That is a wonderful question, Senator.

I think the biggest thing on my plate as the NASA Administrator as we go forward is leading a sustainable return to the Moon. And I do not even like to use the word "return." To go forward to the Moon sustainably. So we have seen what happens with reusable rockets. The cost goes down and the access to space goes up. We want the entire architecture between the Earth and the Moon to be reusable. We want tugs that go from Earth orbit to lunar orbit to be reusable. We want that Gateway in orbit around the Moon to be there for a very long period of time. Think of a reusable command module. So it will be there reducing costs because it is, in essence, not permanent, but it will be there for 15 years. And we want reusable landers that can go back and forth from the Gateway to the surface of the Moon. The more the architecture is reusable, the longer we are going to be able to take advantage of the resources of the Moon and explore more parts of the Moon than ever before.

The other thing—and this is Space Policy Directive-1—commercial partners, international partners, sustainable architecture to the Moon. Take all of those capabilities—and this is a key part, and I heard this, of course, from Senator Nelson. Take all of those

capabilities and replicate them at Mars. The Moon is our proving ground for the ultimate goal which, sir, you have identified as well, which is we are going to Mars. The Moon is our path, the best way to get there to retire risk so we can have mission assurance getting to Mars. So focusing on those areas, the integration of international partners and commercial partners into a sustainable architecture I think is important.

I know, Senator Cruz, you have been very laser focused on the regulatory environment surrounding space. That is going to be tremendously helpful because this architecture is going to take advantage of all of our commercial partners. NASA will be able to buy services because there is a robust commercial marketplace where we are one customer of many customers rather than the purchaser, owner, and operator of certain systems. That drives down costs, increases access. So reforming the regulatory regime I think is important as well.

And of course, another area that this Committee I know has been focused on is the space situational awareness and space traffic management challenges that our country has. Certainly we have astronauts. We are the only agency in the Federal Government that has humans in space threatened by the orbital debris that exists. So I think it is critical that we focus on that as well.

The closest alligator to the canoe right now, sir, is launching American astronauts on American rockets from American soil for the first time since the retirement of the Space Shuttle. That is the one thing I am focused on more than anything else because we need to make that happen by the middle of next year. We are on track to do that and we are focused on it.

So those would be my biggest takeaways.

Senator CRUZ. Well, and I had the opportunity to join you at Johnson Space Center for the announcement of the first commercial crew of astronauts that will be launched on a U.S. rocket from U.S. soil, and that is a major milestone to return to for NASA.

Mr. BRIDENSTINE. Yes, sir.

Senator CRUZ. You talked about, with respect to the Moon, sustainability. Is it NASA's intention to construct a habitat that would be sustainable on an ongoing basis on the lunar surface? Is that part of the plan?

Mr. BRIDENSTINE. The answer is yes. Immediately, no. The first thing is we have to put what we call the Gateway into what we call a near rectilinear halo orbit around the Moon. So that is an orbit where it is balanced between the gravity well of Earth and the gravity well of the Moon. And because it is balanced, it can stay there for a long period of time.

But interestingly, it is also going to have propulsion, solar electric propulsion, which means it can not only stay in that halo orbit that is going to be equatorial in nature, but it can also go to the L-1 point and the L-2 point giving landers more access to more parts of the Moon than we have ever seen before.

This is an important point. 1969 we landed on the surface of the Moon. Up until 2008, we did not know if there was water on the surface of the Moon or not. People argued that maybe there was, but we had no definitive proof. In 2008, we learned that there was.

2009, we now know that there are hundreds of billions of tons of water ice on the surface of the Moon.

So this architecture—in my opinion, sir, the best place to start is getting more landers and more rovers and more prospectors to more parts of the Moon than ever before so that we can discover and learn things that we did not learn from 1969 to 1972 when we were landing in the equatorial regions.

If we go direct to the habitat on the surface of the Moon, we run the risk of learning a whole lot about one spot on the Moon. And given the constraints of the budget, it is my assessment that we need to have more access to more parts of the Moon. And humans would certainly be part of that, but not necessarily a permanent human presence. Of course, in the long term, yes. And the architecture is open, which means commercial partners—they can build their own habitats. And in fact, a lot of them right now are raising private capital to do just that, which we love because then we could, in essence, be a customer of that habitat for NASA's exploration and research as well.

Senator CRUZ. And describe to this Committee and the American people the importance of water on the Moon for sustainability and human habitation?

Mr. BRIDENSTINE. Yes, sir. A wonderful question.

So water represents, of course, drink. You know, we get to drink this. It keeps us alive. But it is also hydrogen and oxygen. Oxygen is air to breathe. And if you think about what powered the space shuttles, for example, rocket engines. It was liquid hydrogen and liquid oxygen that powered the Space Shuttle. In fact, our vehicles today that we are building, the Space Launch System is powered with liquid oxygen and liquid hydrogen. So water is life support, but it is also rocket fuel. And if we can figure out a way even commercially where NASA would be a customer, commercially people could harness the water ice of the surface on the Moon, put it into orbit in cryogenic form, you know, highly pressurized, frozen form, solid form—or I should say liquid form. That liquid hydrogen and liquid oxygen could be, in essence, a fueling depot in orbit around the Moon.

The glory of the Moon, unlike the Earth—the Moon has no atmosphere. So if you look at the things that we launched off the Moon back in the 1960s–1970s—those items—you would never see anything like that launch off the surface of the Earth. Why? Because there is no atmosphere on the Moon. And the gravity well is one-sixth that of the Earth. It is easy to get things off the surface of the Moon. It is very difficult to get things off the surface of the Earth. So when there is an asset, a natural resource like water that is on the surface of the Moon—and we know it is there in hundreds of billions of tons—in my estimation we should utilize it.

Now, again, this is kind of science fiction in the future, kind of thinking about the future, but if we could, then we could, in essence, reposition satellites in geostationary orbit around the Earth using fuel from the Moon, which would be potentially in the future less expensive than using fuel from the Earth. And I am not saying that it is. This is something to think about in the future. But there are natural resources on the surface of the Moon.

The other thing that is important to note, Space Policy Directive-1 says for the first time in American history, we are going to utilize the resources of the Moon. We are going to utilize that water ice. We now know, because of the research NASA does, that there is water ice on the Moon, and in fact, there is new water being created every day from charged particles coming from the Sun impacting the regolith on the Moon. Now, we are not creating tons of ice or water on the Moon. That is not happening, but there is a hydrocycle. There is a water cycle on the Moon that a number of years ago we did not even know existed.

What else do we not know about the Moon? And that is why I think it is so important to go to more parts of the Moon than ever before.

We know there are rare Earth metals on Earth. Those rare Earth metals are not Earth metals at all. They are asteroid impacts from a very long time ago. And we know that the Moon probably went through the same debris fields that the Earth went through back in those days, which means could there be those kinds of metals on the Moon where there is not an active geology, where there is not an active hydrosphere? Could those rare Earth metals be there? I do not know. NASA does not know. In fact, nobody knows. But if there is potentially trillions of dollars of that activity there, it would make sense. That could change the balance of power on Earth. And of course, that is why a lot of private companies are raising money to go to the Moon. That is why other countries around the world are focused on the Moon. So I think it is important for us to know and be the first.

Senator CRUZ. One final question. So the report that NASA submitted to Congress outlines a plan to return to the lunar surface no later than 2029. Now, I would note President Kennedy's speech at Rice that has been referenced multiple times today was given on September 12, 1962 calling for our country to go to the Moon within a decade. And seven years later, Neil Armstrong would step foot on the lunar surface on July 20, 1969.

So help this Committee understand why it took seven years in the 1960s to get to the Moon, and yet today it is going to take until the end of the 2020s?

Mr. BRIDENSTINE. A wonderful question. And, Senator, just so you know, that is the first question when I showed up at NASA. Why is it taking so long? There are a couple of things that are colluding here.

Number one, you know, back then, if you look at real dollars, the budget of NASA was about \$50 billion annually. Right now, we are talking about a \$21 billion annual budget. So it is a lot less of a budget.

The other thing that is important to note is what we are doing now is entirely different than what we did back then. Back then, it was a space race. We were trying to defeat the Soviet Union by getting there first, proving our technological superiority, proving our economic and political superiority in conjunction with that, in essence, space race victory.

What we are doing today is entirely different, and we are the only country on the face of the planet that can lead this effort and that is this. 1969 to 1972, we had six missions land on the surface

of the Moon with 12 people. And then we came home and we have not been back since.

What Space Policy Directive-1 says is, we are going to go to the Moon and we are going to go sustainably. In other words, we are going to build an architecture where we can go back and forth. And we are going to have landers and rovers and robots and humans with access to the Moon, more access to more parts of the Moon than ever before utilizing, because of the budget constraints, utilizing international partners and utilizing commercial partners with an open architecture where the United States of America is in the lead, and then others can build parts or pieces and ultimately advance our agenda, which is to lead in space.

So what we are doing is different, a sustainable architecture where we can get to more parts of the Moon, going to the poles, and learning more than we have ever been able to learn before and, at the same time, doing it with a budget that is much less.

So when you do the analysis—and we just went through a process at NASA where we did the analysis—the question is how is it that given the advances in technology, the miniaturization of electronics, how is it that we are not able to do more than we did in the 1960s? And the answer is, we are doing a lot more than we ever did in the 1960s, and we are doing it with a budget that is a lot smaller.

Senator CRUZ. Thank you.

Senator Markey.

Senator MARKEY. Thank you, Mr. Chairman.

By the way, that was a very interesting discussion. I think that everyone who heard it was given a lot of information that helps them understand the perspective of where we are today.

But as we strive to reach faraway planets and see beyond the stars, we cannot neglect our understanding of our own tiny, little blue dot that we live on. The President's Fiscal Year 2019 Budget Request attacked several decadal recommended Earth science missions, cutting funding entirely for some key climate science projects.

Mr. Bridenstine, do you agree with the recommended cuts to climate science in the Fiscal Year 2019 budget request?

Mr. BRIDENSTINE. So a couple of things to note. The Earth Science Budget of NASA in the President's Budget Request for Fiscal Year 2019 was higher than 3 years of President Obama's budget request. So I want to be clear that we are committed to studying planet Earth at NASA, as we always have been. It goes back to 1958. NASA has been involved in studying the Earth as required by law since 1958.

Some of those programs that you mentioned, Senator, CLARREO, I think PACE was one of them, OCO-3—OCO-3 is being launched in January. It is funded. It is done. CLARREO and PACE are, because of the laws passed by this body—they are being built as we speak. It is my goal as the Administrator of NASA to follow the decadal surveys that we get from the National Academy of Sciences, and that is my objective, to make sure that what we are doing is apolitical and nonpartisan.

Senator MARKEY. So you are not going to reject the decadal recommendations?

Mr. BRIDENSTINE. No, sir.

Senator MARKEY. But the administration's budget in essence does. So how do you square that?

Mr. BRIDENSTINE. So I do not think that it does reject the decadal survey. What we are trying to do is follow the guidance of the decadal survey that says what Earth science information we need to collect. And that is ultimately what we are doing.

Senator MARKEY. So the second ever decadal survey for the Earth Science Directorate was released in January of 2018. As it notes, earth science provides an essential information infrastructure element for our society. This work is used in everything from land use planning to the data in your weather app.

Mr. Bridenstine, how are you working to implement the recommendations of the Earth Science Decadal Survey, including innovative new missions to study how our planet is changing from the vantage point of space?

Mr. BRIDENSTINE. That is a wonderful question. And the only way we can understand our changing planet—and our planet is changing—is to study it from space. So we have satellites that can look at the hydrosphere and the atmosphere, even the ionosphere, the lithosphere. All the different spheres within the Earth's system are being evaluated by satellites built by NASA. And because we have made these investments and we continue to make these investments, we are getting a better understanding of planet Earth than ever before.

I think there is broad bipartisan agreement that we need to understand what is happening to our planet. And it is my objective, as the NASA Administrator, not to delve into how to deal with what we find, but to deliver dispassionate science so that policymakers can make decisions on it.

Senator MARKEY. So, Mr. Bridenstine, do you support the recommendation that NASA create new competitive mission categories that would fly lower cost Earth science missions and help scientists continue critical earth science observations over a longer period of time?

Mr. BRIDENSTINE. Yes, I do. I think we need a balanced portfolio, Senator. So we need flagship missions, big missions that are capable of doing very exquisite science. We need medium class missions and smaller missions. There is risk in big missions, a lot of dollars involved, and if they are not successful, then it is a failure and it costs a lot. So we need a balanced portfolio. But the answer is, yes, sir, I do. I do appreciate the question and we will continue to invest in those smaller missions.

Senator MARKEY. So with Earth sciences, NASA does not have to choose between the inspirational and the practical. And in a twist on the old saying, we can keep our eyes on the ground while our feet are in the stars—and that is something that it is good to hear you comment on.

In my opening statement, I talked a little bit about your views on climate science. I would like for this Committee hearing, if you could, to talk about that subject as you did before the Appropriations Committee so that we can have that on record here as well.

Mr. BRIDENSTINE. You bet.

So carbon dioxide is a greenhouse gas. I do not know anybody—no scientist for sure—that would reject the notion that carbon dioxide is a greenhouse gas. It is prevalent in our atmosphere and now it is more prevalent than ever before because of human activities. And so it is without question that human activities are contributing to the global warming that we are seeing.

Senator MARKEY. NASA scientists have concluded that it is the dominant cause of the warming. Do you agree with that finding?

Mr. BRIDENSTINE. I have no reason to reject that analysis.

Senator MARKEY. Well, that is important to hear.

And you committed to protecting scientific integrity at NASA?

Mr. BRIDENSTINE. Yes, sir.

Senator MARKEY. Can you give us some examples of how you have worked at NASA to counteract the reported fear that scientists feel across our Federal agencies at this time when it comes to the subject of climate science?

Mr. BRIDENSTINE. So NASA scientists have permission from me and, of course, they did before and they still do, and I have not done anything to change that. They have permission to speak at symposia. They have permission to write op-eds. They have permission to put what they learn—you know, make it public, and we support that. If there are other scientists within NASA that want to disagree with the assessment, they have the freedom to disagree with whatever that assessment is. I believe in transparency and openness. So I am 100 percent in support of giving people the ability to speak their mind as it relates to science.

Senator MARKEY. And they are super, super talented people.

Just to go to the Chairman's comment, my grandmother died when my mother was a junior in high school. And as a result, although she was going to be Class President and top girl in her class, she had to stay home to be the mother to the three younger girls, and then one older sister went off to work.

So when I was growing up, the younger sisters all had children before my mother because she is still at home. And one of the sisters had a son, seven years older than me, who was such a brilliant student in physics that when President Kennedy gave that speech at Rice University, he went off to NASA.

And the oldest child of one of the other sisters—she was a brilliant math student, and in this movie, "Hidden Figures," they talk about the Fortran program at IBM. And so she was one of the first five women in the Fortran program at IBM that was documented in this movie, "Hidden Figures."

Then I come along with no scientific ability at all, which was a disappointment to my mother. However, I hear President Kennedy's statement, and so my goal was to ensure that we fund the scientists, the mathematicians, the computer geniuses who can accomplish these goals, which is what this Committee is all about. It is to evaluate the programs, to ensure that the money that the Federal Government is appropriating is being used in a way that helps to advance our goals as a nation and as a planet.

And so I am very interested, Mr. Administrator, just in ensuring that there is no discouragement to these brilliant people. I was related to them. I was told that I should be like one of them. I cannot be. They have a gift and they give that gift to the United States

when they go to work at NASA. It is an incredible gift, and we do not want any of them to feel, at any time, that they are threatened because they have done work that just reached a correct scientific conclusion.

Mr. BRIDENSTINE. I agree.

Senator MARKEY. Thank you.

Mr. Chairman, thank you.

Senator CRUZ. Thank you, Senator Markey.

Administrator Bridenstine, China has announced their intention to have an operational space station in low earth orbit by 2022. Do you have concerns that if the administration were to de-orbit the ISS in 2024 that China could have the only operational platform in low earth orbit?

Mr. BRIDENSTINE. It is a big concern. But to be perfectly clear, there is no plan to de-orbit the International Space Station. So if that was the case, the answer would be very concerned.

What we want to do is transition to commercialization of low earth orbit. Again, if NASA can be one customer of many customers, it drives down our costs. And if we have multiple providers that are competing on both cost and innovation, we see what happens. When we had launch providers competing on cost and innovation, for the first time we are seeing these rockets launch and then come back and land, and then we use them again. And because they are proven, insurance rates are actually lower than they would have been for a new rocket, which is an amazing kind of—you know, I did not predict, a lot of people did not predict that we are building certainty and at the same time saving money.

Imagine, Senator, when you flew to Washington, D.C. from Houston, Texas, when you got here, you had to throw the 737 in the trash. That would be a very expensive plane ticket. But because we can reuse airplanes over and over again, it drives down the cost. It increases access. Now the whole world can fly.

We are trying to do the same thing in space. And we are doing it right now with launch, and we are seeing a lot of success but it is because, quite frankly, we heard Senator Nelson talk about how the United States of America is now the largest exporter of commercial launch. And in fact, we are not just the largest, we are larger than the rest of the world combined at 57 percent predicted. This year it would be 65 percent. So that is a wonderful thing.

The question is, why did that happen? It is because NASA said we want to buy launch as a service, and we want you providers to compete on how you are going to compete on how you are going to sell us your service. Instead of purchasing, owning, and operating our rockets, we want to pay you for the service, and we are going to be one customer of many and we want you guys to compete on price. All of a sudden, we are seeing reusable rockets. Now launch is an export for the United States of America at a time when we have right now in this country a massive trade deficit. So that is a positive thing, and NASA is a big piece of why that is.

The question is, can we replicate that in low earth orbit? And there are companies that are interested internationally building consortia that could maybe operate the International Space Station commercially. Is that possible? I do not know.

But what we have done—and I think this is an important point—we have forced the conversation to take it very seriously. There was a time at the end of the Apollo program and before the Space Shuttle program where we had 6 years where we were not launching into space. And of course, now that the retirement of the Shuttle is complete and we do not have a commercial crew yet, we have got an eight-year gap. What we want to do is avoid any gap in low earth orbit. We know that there is a definitive life for the International Space Station. We do not know specifically when that is, but what we want to do is make sure that we are prepared to avoid any gap in low earth orbit. So, sir, your point is very well made, and we are thinking about it all of the time at NASA and within the administration.

Senator CRUZ. I want to clarify two points on your answer.

Number one, you agree that it would be completely unacceptable for the only operational platform in low earth orbit to be China's.

Mr. BRIDENSTINE. Yes, 100 percent.

Senator CRUZ. At any point in time, we cannot cede low earth orbit to China.

Mr. BRIDENSTINE. Yes.

Senator CRUZ. We have also heard testimony from multiple witnesses before this Subcommittee that as a matter of the science, as a matter of the structural integrity, that the ISS is usable at least until 2030. Do you agree with that assessment from a scientific and technical perspective?

Mr. BRIDENSTINE. It is probably possible, yes. The question is, how much risk are we assuming and what is the cost of making that happen? And so it is technically feasible to keep it alive to 2030 and maybe even beyond that. Technically it can be done, yes.

Senator CRUZ. We talked earlier about the impact—about the objective is going to the Moon and a lot of exciting things about there. But as I said in my opening statement, I want to make sure the Moon does not distract from the ultimate objective of Mars.

Can you describe how going to the Moon is useful for the mission of going to Mars and how we will keep the focus on Mars and not get distracted by the intermediate step?

Mr. BRIDENSTINE. Yes, sir. That is a wonderful question.

The intent is to get to Mars. And how do you get to Mars? Well, we have this proving ground. And I think probably the best way to characterize it—we are all familiar with Apollo 13. It was a NASA failure but also at the same time an amazing NASA success. Why was Apollo 13 a success even though it was a failure? It was because there was a technical problem that would have been catastrophic on the way to Mars, but because they were on their way to the Moon, they were able to get home.

The glory of the Moon is that it is only a three-day journey home. So we can prove all of the technologies. We can reduce all of the risks. We can try all of the different maturations that are necessary to live and work on another world, and we can do it all at the Moon where, if there is a problem, if there is an emergency, we know that we can get people home.

The challenge with Mars is that if we go there for the first time—and there is the other challenge, not just the technology and the retirement of risk technologically. The other challenge is

human physiology. We know, based on what we have learned on the International Space Station, that our astronauts—they lose 1 to 3 percent of their bone mass every month on the International Space Station. Their cardiovascular system becomes deconditioned. Their neurovestibular system, of course, gets thrown out of whack to the point where sometimes it takes weeks if not months when they get back before they can even drive a car again in some cases, not in all cases, in some cases. We know that their immune system is very challenged and stressed in a microgravity environment to the point where it is very easy to get sick in a microgravity environment. And we know, of course, when you go beyond low earth orbit, there is this radiation environment that can have effects on the human body that we are still learning about. Of course, we do not want to use humans as the test case for that. So all of these physiological changes and understandings we have learned from the International Space Station while we have humans there for a period of 6 months and in at least one case up to a year in low earth orbit.

Now, imagine a seven to nine month journey to Mars with all of those physiological challenges happening, and then when you get to Mars, you have to live and work. You have to be perfect. You cannot make a mistake because if you do, you will not live. And all those physiological changes and challenges—and then when you get there, you cannot come home for at least two and a half years because Mars has to be in line with the Earth before you can make that journey home. So it is about a two-year, 26-month evolution before you can come home, and of course, then you have got a six-month journey home. So this presents a challenge where do you really want to test all of this out for the first time at Mars? Or can we prove it and test it out on the Moon and that in fact would accelerate our path to get to Mars?

So it is technology. It is physiology. The Moon is the proving ground and Mars is the goal. So I think that is the reason we go to the Moon.

Senator CRUZ. So in my device it says please do not leave Matt Damon behind when you get to Mars.

[Laughter.]

Senator CRUZ. Three more questions. One, can you just confirm, as Senator Nelson made reference to in his opening remarks, that the objective is not simply to orbit Mars, but it is to land and have an American boot on Mars and plant an American flag on Mars and begin exploring Mars?

Mr. BRIDENSTINE. Yes, sir. That is why we go to the surface of the Moon. The Moon is very different than Mars in the sense that Mars has an atmosphere. So landing on Mars is far more difficult than on the Moon. I know that sounds weird. They have an atmosphere. Why would that be harder? Well, when you have to reenter into an atmosphere and the velocities at which you are traveling, it becomes a very complicated scenario.

Now, here is the good thing. The United States of America is the only country that has successfully landed on Mars. We have done it seven times, and we are doing it again November 26, the Monday after Thanksgiving at 11:00 a.m. So that is going to be another big day for the United States of America.

So all of that being said, there are differences between the Moon and Mars, but we do want to get to the surface of Mars. And so we want to replicate as much as we can from the Moon. We want to prove and test as much as we can at the Moon. And then where we need to make changes, while we are doing that at the Moon, we are going to be developing the technologies and capabilities for Mars.

You know, we talked about the Gateway, which would be in orbit around the Moon. Think of a reusable command module that our landers can go back and forth from to the surface of the Moon. We think about the tugs from Earth orbit to lunar orbit.

That Gateway—you know, the first one is a technology demonstrator. It is about proving capability. It is about NASA learning how to do this again.

The second one—and there is no decision that has been made on this. I am just thinking visually like what is the second one. Well, the second one could very well be a deep space transport. That is our path to get to Mars.

So what we do at the Moon is critically important for going to Mars, and a lot of the experts that you talk to at NASA would say we cannot get to Mars without going to the Moon.

Senator CRUZ. Last month, I was joined by Senator Cornyn and Representatives Babin, Culberson, and Smith in sending you a letter requesting that NASA's Johnson Space Center serve as the lead center for NASA's lunar lander program. In my opinion, JSC is a natural fit for the program given that JSC has historically served as the lead center for human space flight for more than half a century.

Has NASA made any decisions pertaining to how it intends to set up the lunar lander program?

Mr. BRIDENSTINE. You are really trying to make me make news. Are you not, Senator?

Senator CRUZ. I am doing my best.

Mr. BRIDENSTINE. First of all, Johnson Space Center, a critical part of all of our lunar activities, will be part of the Gateway, part of landers as well. As far as what centers are going to have what responsibilities, we are going through a process right now to evaluate all of that. Just know that Johnson Space Center is going to be a critical piece of that, but I am not ready to announce what their particular position will be.

Senator CRUZ. Final question. Last month, I introduced legislation and was joined by Senator Markey, Senator Nelson, Senator Thune. The legislation was called the "Hidden Figures Way Designation Act." And it was legislation to rename the street in front of NASA's headquarters here in Washington, "Hidden Figures Way" after the incredible pioneers, the African American mathematicians who blazed the way for our going to the Moon.

The D.C. City Council Chairman Mendelson introduced a companion bill last week that was joined by all 12 other council members, so a unanimous companion bill to rename the street in a strong show of support for every woman who has worked for NASA as a human computer.

It is likely that the street in front of NASA headquarters will be designated as "Hidden Figures Way" before the end of the year.

In your judgment, what will the new street name mean for the culture and for the employees at NASA?

Mr. BRIDENSTINE. It is a wonderful question, and it is an important part of who we are as an agency. As you are aware, NASA is probably the single most inspirational Federal agency that we have, and if you walk around the headquarters building and you ask people that are old enough where were you when Neil Armstrong and Buzz Aldrin walked on the Moon, they will tell you right where they were and they will tell you how it changed their lives, the education that they got because of it, and ultimately how they ended up at NASA. It was transformative.

And yet, we know the names, Neil Armstrong and Buzz Aldrin. Katherine Johnson was responsible for calculating the orbital trajectory for John Glenn, which of course was another critically important mission. But there are so many—I think when we landed on the Moon, the number of people that were involved in that project at the time was around 400,000. I mean, that is a lot of people, and they are all critically important to what NASA is and what NASA does in the accomplishments of our country.

And as you have rightly said, so many of them were hidden, and the more we can give them credit and show them how they contributed—show the next generation how they contributed, that is what it is all about. We want to inspire that next generation. We want to attract the absolute best and the brightest that America has to offer, and so many of those people that were at that time hidden are now going to be those moments of inspiration for the next generation.

The summer between my fifth grade and sixth grade year, for the first time my mom put me in a summer camp where we got to play with a wind tunnel, and I got to play with the camber of a wing. I learned about Bernoulli's theory, and it changed the direction of my life. I knew from that week forward I was going to be a pilot. It did not matter what I did for the rest of my life. I knew I was going to be a pilot. And so that had a transformational kind of impact on me. And then as I eventually ran the Tulsa Air and Space Museum, I saw children have their lives transformed because of experiences they had with the volunteers and others at the Tulsa Air and Space Museum.

So those kind of impactful things I think are important for developing the next generation of STEM in this country. And the reason that is so important, the country that controls the technology, controls the balance of power on earth. And that is true going back to the beginning of time. Whoever controls technology controls the balance of power. That means our people here in the United States—we have to be preeminent in technology. So the more we can inspire that next generation into STEM, we need to do so. I think it is a great idea.

Senator CRUZ. You sound like you were a precocious fifth grader.

Mr. BRIDENSTINE. Yes, right.

Senator CRUZ. You and that Bernoulli fellow.

Senator Gardner.

**STATEMENT OF HON. CORY GARDNER,
U.S. SENATOR FROM COLORADO**

Senator GARDNER. Thank you, Mr. Chairman.

I am like the guy who shows up right when everybody wants to go to bed and wants to have a long conversation. So I will keep this quick and short. I apologize for being late.

We have talked about dates and where were you, and I remember where I was on I think it was the 8th of July in 2011. And I was in the House caucus room, the Republican caucus room off the floor of the House of Representatives, and there were probably 30 or so, 40 Members of Congress. And we were watching TV and we were watching the last launch of the Space Shuttle. And I remember watching that thinking this is great. We are all watching this. This is bringing America together to celebrate the last human space flight from this country. We did not know when it was going to start again. We did not know what was going to happen.

And so I appreciate the work you have done on the Orion project and others and Mars to help us retain that vision so that when I looked around that room in that cloak room, not caucus room—I am sorry—cloak room and I wondered was somebody not going to do something about this, thank you for doing something about this. Thank you for working with Congress to do something about this.

And when you said that your mom had taken you to a wind tunnel, I did not realize she was the one that forced you to run for Congress.

[Laughter.]

Mr. BRIDENSTINE. That happened later.

Senator GARDNER. It was summer camp. I am sorry.

So with that, Mr. Chairman, thank you very much. Administrator Bridenstine, thank you for your leadership.

Mr. BRIDENSTINE. Thank you.

Senator CRUZ. Thank you.

Senator Markey.

Senator MARKEY. Thank you.

This is the third hearing that Senator Gardner and I have been at together mostly asking questions at the end of those hearings. That has been our day. Thank you.

I just have another couple of questions.

The President's budget request proposed to merge the Space Technology Mission Directorate into the Human Exploration Directorate. Merging these functions can force us to abandon or choose between key functions that NASA currently performs.

Do you agree that the Technology Directorate does invaluable basic research in advancement areas other than human space exploration?

Mr. BRIDENSTINE. Absolutely yes, sir.

Senator MARKEY. I have heard reports that there are other arrangements up for consideration that would keep the Technology Directorate largely intact.

Mr. Bridenstine, are you considering any organizational options that would preserve the Technology Directorate?

Mr. BRIDENSTINE. The answer is what we are doing right now is we are going through a process, and there are a lot of pieces to this process that would include—we had direction from the administra-

tion to look at how FFRDCs play into NASA's mission, you know, the federally funded research and development centers. We have direction to look at some other things to include independent assessments and those kind of things. So what I am doing right now, we are going through a process.

Senator MARKEY. Are you considering any options that would preserve the Technology Directorate?

Mr. BRIDENSTINE. We are looking at all options, yes, sir.

Senator MARKEY. That is good.

In a hearing earlier this year, Dr. Dava Newman talked about the importance of promoting synergies between science, technology, and human exploration. The need to promote these synergies is obviously important so that they are not suppressed. So I would hope that you would consider preserving that Technology Directorate.

And finally, we did not understand how much James Webb's Space Telescope would cost until halfway through its mission development, and we were recently told it would be more expensive still. This uncertainty makes it hard for scientists to make informed decisions about how to prioritize different missions in the decadal surveys.

How is NASA working to improve mission concept development to ensure that we have a better idea at the outset of what these projects are going to cost?

Mr. BRIDENSTINE. It is a wonderful question, sir.

You know, James Webb Space Telescope is, of course, a big challenge for us right now because we have had this cost overrun and this delay. We are putting in place—we called for an independent review team I guess it was at this point probably about a year ago. That independent review team has done its work. We are now implementing all of their recommendations. There were 32 recommendations—30 of them we have already implemented. We are working through a couple more.

But the key thing to remember I think that is important is what NASA does is we do things that have never been done before that are technologically very difficult and really, in some cases, very difficult to even define ahead of time.

So with James Webb, we are looking back to the very beginning of time. We are looking back to the very beginning of the universe, the very first light that existed in the universe. And it is being done in infrared, which means it has to be an extremely, extremely, almost zero Kelvin kind of infrared telescope. So there are a lot of technologies that had to be invented along the way, many of which we did not know what the cost would be at the time. So we have had this overrun.

Going forward, to your question, sir, we have to look at the portfolio that we have and have a balanced portfolio. You mentioned smaller missions earlier. If we can look at a balanced portfolio where we want to have that flagship mission that is critically important, technologically superior and puts the United States number one in the world in physics.

Senator MARKEY. Exactly. And that is kind of what the goal is here. Right?

Mr. BRIDENSTINE. Yes, sir.

Senator MARKEY. Small investments in a timely fashion would make it possible for NASA to work smarter not harder. And when a budget doubles, it is coming out of something else, and something else in many instances is the vision that we would have had to accomplish bigger things, you know, challenge our country to what is possible from NASA.

So I would just recommend to you, that you as the Administrator, just go back and just start examining more closely each of the premises that people have because ultimately we are budget constrained. We can, obviously, afford some increases in NASA's budget, but we are largely willing to fund consistent with the vision. But when a previous vision just gets bigger and bigger in terms of its budget allocation, it just makes it harder here. So we want to be as helpful as we can. So I just make that recommendation to you.

Mr. BRIDENSTINE. Thank you.

Senator MARKEY. Thank you.

Senator CRUZ. Administrator Bridenstine, a couple of questions.

We spent a lot of time in this hearing talking about the objectives for NASA and the need for expenditures. I want to talk a little bit about the objectives for NASA and the need for expenditures. I want to talk a little bit about the revenue side and increasing the resources NASA has available to do this.

The *Washington Post* has reported that requests from individuals and companies to use NASA's logo on T-shirts and other commercial items is getting a lot of interest. For example, there is NASA-themed apparel made for Target, Old Navy, Lands End, Coach, and H&M. The designer, Heron Preston even sells a NASA T-shirt for \$270.

Despite this commercial interest, NASA right now does not make anything on the sales of products using its logo. Do you agree with this policy, and has NASA taken any steps to receive compensation off the sale of the agency's logo?

Mr. BRIDENSTINE. That is an important question.

So the answer is we have a logo. We have a right to that logo, and because we have the rights to that logo and somebody else finds value in it, they should pay for the rights to use that logo. I get that.

And I will be honest. I do not know if anybody has bought the rights to use that logo or not. I do not know. I have not looked into this issue. I have noticed, as you have, I am seeing a lot of NASA T-shirts on the streets. I will tell you I have found that personally, as a source of pride, that people are so interested in it. And I have not made any effort to try to quell it or squash it. That does not mean that we should not. And I will be honest. I do not know what the right answer here is. If you have any ideas, I would be more than thrilled to listen to them. But in my view, I love the fact that I see so many NASA logos on the streets.

Senator CRUZ. Well, for what it is worth, I agree with you that it is a great thing that people are excited about NASA, that they are wanting to wear NASA clothing, but I also think that NASA should be compensated for it. And I am a believer in commercializing and seeking revenue streams. Look, I can tell you I have

never owned any T-shirt that cost \$270, and by the way, having seen your wardrobe, I am pretty confident you have not either.

[Laughter.]

Senator CRUZ. But if somebody is paying \$270 for a T-shirt, a chunk of that ought to go to NASA and actually help fund getting to the Moon and getting to Mars.

A related point in terms of commercialization, earlier this year CASIS testified before our Subcommittee that more than 55 percent of payloads to the national lab are private sector customers, which includes projects from iconic Fortune 500 companies and innovation startups.

Now, I want to be clear that I support having vast amounts of research conducted on ISS, but given that the American taxpayers are subsidizing the transportation cost to and from station, astronaut crew time to conduct the experiments, and the operational and maintenance costs of the national lab, it is worth a close examination of how research is being conducted right now and if there is a need to alter current research agreements.

A few specific examples. Goodyear is using microgravity to better understand silica morphology for manufacturing new tires with low rolling resistance that are more fuel efficient and safer. CASIS's material states that, quote, research could give Goodyear a competitive advantage in the tire industry by developing superior rubber materials.

Another example. Merck is using microgravity to grow a crystalline suspension of millions of tiny uniform crystals to improve the formulation of the company's cancer immunotherapy drug Keytruda. Keytruda is the drug that made former President Jimmy Carter's cancer go into remission, and Forbes has reported that some analysts predict that Keytruda may be Merck's next \$10 billion drug.

Administrator Bridenstine, do you believe that NASA and Congress should reexamine these agreements to ensure that the American taxpayers are receiving fair compensation for the research that is being conducted by iconic Fortune 500 companies and that may result in giving these companies a competitive advantage in their respective industries?

Mr. BRIDENSTINE. Yes, I do believe those kind of programs and opportunities on the International Space Station—we need to reexamine those. And I intend to do that as the new Administrator. In fact, we are. We are looking at it right now.

It is also important to note—and I think this is an important point to make—we want those kind of activities happening inside the United States of America. There is no shortage right now of enthusiasm on the part of our largest peer competitor China to have these activities going on on their space station that they are building for the future.

So the answer is yes, we need to examine it. What we do not want to do is we do not want to damage the commercialization of low earth orbit because we are charging for something that they can get for free in a different country. And so we have to be really careful about how we balance that, but certainly it is something to take a look at.

Senator CRUZ. And I think that is a fair point and concern you raise and something that I look forward to continuing to work with you on. It seems to me we have many research universities in the United States that have very successful commercialization programs where there is innovation and research being conducted in the universities, and the universities in turn receive a portion of the profits. And that helps fund even more innovation, even more research. And that is a model, it seems to me, NASA should look at given the enormous potential. But you are right. We certainly need to look at it within a framework of a competitive environment in China and other nations potentially as competitors.

Mr. BRIDENSTINE. I would also add both of these items that you brought up, whether it is activities happening on the International Space Station that could potentially result in big profits for corporations terrestrially, I think that is an important thing for the United States to be leading in, and even something as simple as the NASA logo. These are ideas I think that we need to be considering.

It is also important—and I would love to work with you on this. As you are aware, appropriators guard very jealously appropriation dollars, and to the extent that we were to receive some kind of proceeds from those activities—and maybe there is an opportunity to do that and we should be doing it. My concern would be NASA would be doing all the work, and then those proceeds could end up going to the general Treasury. And look, I want to retire the deficit as much anybody else. But I would love to see us utilize those proceeds for the advancement of human spaceflight, for the advancement of our science, for the advancement of understanding our planet. These are the activities that I would love to see those proceeds going toward and not necessarily just going into the general coffers.

Senator CRUZ. Well, unsurprisingly, you and I are on the same page on that, and indeed, much of my interest here is to generate a revenue stream that can be dedicated directly to space exploration to ensure that we have the resources to continue America's leadership going back to the Moon and ultimately going back to Mars and ensuring that we have sufficient investment and that we are also in a position where we are leveraging billions more in private investment as well. And so I look forward to continuing to work with you on that.

Administrator Bridenstine, thank you for your testimony. Thank you for being here. I think this was a productive hearing.

The hearing record will remain open for two weeks. During that time, Senators are asked to submit any questions for the record. Upon receipt, the witness is requested to submit your written answers to the Committee as soon as possible.

And with that, this hearing is adjourned.

[Whereupon, at 3:40 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN THUNE TO
HON. JAMES F. BRIDENSTINE

Question 1. What specific steps is NASA taking in partnership with other Federal agencies to improve space cybersecurity within the agency's domain as called for in the National Cyber Strategy issued September 2018?

Answer. NASA supports the National Cyber Strategy to protect National space assets and support infrastructure from evolving cyber threats by working with other Federal Agencies to strengthen the cyber resilience of existing and future space systems. These efforts include strategic leadership engagement, such as NASA's participation in the National Security Council's (NSC) Space Cybersecurity Working Group. Through this group, NASA actively collaborates with other Agencies and provides input to the National Space Cybersecurity Implementation Plan.

NASA serves as the leader of the 'Cyber Resiliency of Space Systems' goal for the National Space Science and Technology Partnership Forum. In 2015, this inter-agency forum was established by the USAF Space Command Chief Scientist and the NASA Chief Technologist to identify synergistic efforts and technologies between multiple government organizations with space equities, explore ways to collaborate on investments, and facilitate cross-agency engagement. The Forum has 18 Federal agencies participating and sharing best practices and standards for space cybersecurity. The cyber goal is to strengthen space system cybersecurity across the U.S. Government through activities including cybersecurity analysis and metrics, red teaming, work with cyber test ranges, and government-commercial information sharing. The fourth Technical Exchange Meeting is scheduled at Buckley Air Force Base, Colorado, in March 2019.

NASA collaborates daily with other Federal agencies through its normal processes and agreements as it works to build and operate spacecraft and execute NASA missions. Many of NASA's missions (*e.g.*, Landsat 9) are developed through partnerships with other Federal agencies, and require constant inter-Agency cybersecurity cooperation to ensure the safe, secure and successful achievement of mission objectives.

Question 2. The NASA Office of Inspector General in May 2018 identified that the acquisition of certain IT products from a Chinese technology company was conducted without a supply chain risk assessment and potentially violated the Anti-Deficiency Act (ADA). What is the current state of NASA's review into whether such acquisition violated the ADA? If NASA has determined it did not violate the ADA, why not?

Answer. NASA Office of the Chief Financial Officer (OCFO) concluded its preliminary review of potential Anti-Deficiency Act (ADA) violations for all seven transactions referenced in Recommendation Number 5 of NASA Office of Inspector General (OIG) Audit Report IG-18-019. The OCFO's final Preliminary Review report, issued on September 27, 2018, concluded that no Anti-Deficiency Act violations occurred. The NASA Office of General Counsel (OGC) reviewed and concurred with OCFO's report.

Because the OIG Audit report focused on the NASA Office of the Chief Information Officer (NASA OCIO) Risk Assessment process and cyber-security concerns, the OCFO worked closely with the NASA OCIO in analyzing each of the transactions cited by the OIG that were the focus of potential ADA violations. OCIO and OCFO researched each transaction, obtained and reviewed both technical, procurement, and other Risk Assessment database information, and had OCIO contact the FBI when required. OCIO and OCFO executed all protocols/risk assessments and other analysis required pursuant to OCIO and OCFO policies. This technical information was vital to the determination of whether or not a potential ADA violation occurred because the OIG Audit Report based its conclusions of such potential violations on the absence of "undergoing the required supply chain risk review and approval process."

Of specific concern was the noted purchase of one item, an IT product from a Chinese technology company. Further, the report indicated this purchase violated the “intent” of the 2013 law and, according to the OIG, constituted an ADA violation.

During the Preliminary Review, OCFO found that the purchase of concern to the OIG, the one IT product from a Chinese technology company, occurred after FY2013. OCFO consulted with NASA’s OGC, which advised OCFO that the 2013 law was not applicable and instead, the later and narrower appropriations restrictions applied. Accordingly, only high-and moderate-risk systems were required to undergo the required supply chain risk review and approval process.

As such, OCFO determined the IT product from the Chinese technology company was part of a NASA moderate-impact system, but the required risk assessment was conducted for this purchase back in 2016. The requisite RFI (Request for Investigation) dated June 15, 2016, was approved in July 2016. Additionally, because of the expressed concerns of OIG regarding potential involvement of Chinese companies, OCIO conducted additional research and reconfirmed in August 2018 that this particular item was manufactured in the United States. As such, the purchase of the IT product from the Chinese technology company complied with both the narrower appropriations restrictions and the necessary OCIO Risk Assessment and acquisition protocols. Thus, OCFO concluded there was no ADA violation related to the IT product from the Chinese technology company.

Finally, OCFO’s Preliminary Review concluded the criteria cited by the Auditors for a required Risk Assessment did not apply for the other six IT and communication transactions cited in the OIG report. These purchases questioned by the OIG were not made or incorporated into a “high-impact” or “moderate-impact” system as defined by Federal Information Processing Standards Publication 199, and pursuant to Public Law No. 113–6 and subsequent appropriations, a risk assessment was not a requirement for these purchases. OCFO and OCIO also confirmed the IT assets were either not connected to the NASA system and/or purchased solely for use in Low-Risk systems. Thus, no ADA violations occurred related to these transactions.

Question 3. In 2016, the Government Accountability Office (GAO) called for NASA to improve its security over high-impact systems—systems that could have a severe or catastrophic effect if compromised. GAO deemed these recommendations to be “priority” recommendations for the agency, yet some of the recommendations still have not been implemented by NASA. At the direction of Congress, GAO followed up with a broader look at cybersecurity weaknesses with a report entitled “Urgent Action Needed to Address Significant Management and Cybersecurity Weaknesses.” Is the agency working in an urgent manner to address these cybersecurity concerns?

Answer. NASA is working diligently to address cybersecurity concerns identified in the GAO’s audits on improving security for high-impact systems (GAO–16–501) and taking deliberate actions to address significant management and cybersecurity weaknesses (GAO–18–337). In addition to addressing the recommendations of this report, NASA recently achieved its first “Managing Risk” rating on the OMB Cybersecurity Risk Management Assessment based on the Agency’s FY2018 Federal Information Security Management Act (FISMA) metrics. Key metrics improvements include credentialing and authorization protecting user accounts using PIV cards and intrusion detection and prevention capabilities, achieving 99.8 percent on DHS BOD 18–01.

For GAO–16–501, NASA successfully completed the requirements to close three of five recommendations, as of September 2018. NASA is working to close the remaining two recommendations, which are nearly complete. These two recommendations pertain to: (1) updating security assessment plans to ensure that controls are comprehensively tested; and, (2) updating NASA’s continuous monitoring strategy to include performance metrics. Both of NASA’s selected high-impact systems have mitigated GAO’s technical findings and updated their security assessment plans for future assessments; NASA is working with GAO to provide necessary documentation to validate closure of these recommendations. NASA is updating its continuous monitoring strategy to align with performance measures from the National Institute of Standards and Technology (NIST) and are targeting completion and publication of these measures by the end of January, 2019.

For GAO–18–337, NASA has three cybersecurity management recommendations that are currently in progress. These pertain to: (1) establishing a cybersecurity strategy; (2) establish an information security program plan (ISPP); and, (3) establishing clearly defined security policies and procedures. Enabling all three recommendations, NASA recently hired a Chief Cyber Risk Officer to establish and oversee agency-wide cybersecurity risk management initiatives. Activities currently underway include leading a NASA Cybersecurity Integration Team (CIT) to address key cybersecurity management challenges, clarifying security policies to reflect current practices, and maturing risk management operations. NASA has also com-

pleted the ISPP. The ISPP, after review by the NASA Administrator and OMB, was signed by the NASA CIO on November 1st, 2018. It is now in the publication and Congressional notification cycle. Lastly, NASA's review of its security policy management framework to facilitate consistent reviews is projected to complete by March 2019.

Question 4. Multiple audits issued by the NASA Office of Inspector General, including in February 2012 and more recently May 2018, provided several recommendations to improve the Security Operations Center which have not been implemented by NASA. The OIG found "since its inception a decade ago, the SOC has fallen short of its original intent to serve as NASA's cybersecurity nerve center." What steps has NASA taken to improve the detection and mitigation of cyber incidents across NASA, including strengthening the Security Operations Center?

Answer. NASA has taken multiple steps to address and improve the NASA Security Operations Center (SOC) capabilities, governance and responsiveness. The OIG audit recommendations, including those in OIG-18-020, Audit of NASA's Security Operations Center, are key considerations in these on-going improvement efforts. The improvement actions include establishing a SOC continuity of operations/high availability (COOP/HA) capability that include essential functions, critical services and components, performing an Agency-wide assessment of storage solutions to support Agency incident detection and response capabilities to identify data logging, data analytics and data correlation needs, and developing a charter for the NASA SOC that addresses the SOC's organizational placement, purpose, authority, and responsibilities. Among other governance improvements are the greater direct involvement in SOC operations by the Agency CIO and the Agency Senior Agency Information Security Officer (SAISO). Examples of this include multiple visits by these senior Agency officials to the SOC to assess their operations and work with the Ames Research Center leadership to institute organizational improvements.

The NASA SOC implemented enhancements and improvements in the operations of its three key core cybersecurity services: Monitoring and Detection; Incident Mitigation and Prevention; and Reporting and Communications. Network monitoring was enhanced by implementing and monitoring intrusion detection capabilities, between NASA's mission networks and the Internet, in order to assess the risk of the Agency's high value assets. Endpoint monitoring capability was implemented directly on NASA computers allowing for the detection of compromised NASA systems within encrypted network environments and outside on NASA networks. Leveraging external threat information, the NASA SOC successfully reduced the number of phishing compromises at the Agency through enhanced e-mail protection. NASA SOC implemented an Agency-wide intrusion prevention system that blocks numerous attacks against the Agency's infrastructure daily. These efforts resulted a measured decrease in malicious code infection across NASA, as evidenced by the chart below, showing the incident information for FY17 and FY18.

| Category | Name | Description | Number of FY17 Incidents | Number of FY18 Incidents |
|----------|-------------------------|---|--------------------------|--------------------------|
| CAT 1 | Unauthorized Access | In this category, an individual gains logical or physical access without permission to a Federal agency network, system, application, data, or other resource, including lost hardware. | 745 | 214 |
| CAT 2 | Denial of Service (DoS) | An attack that successfully prevents or impairs the normal authorized functionality of networks, systems, or applications by exhausting resources. This activity includes being the victim or participating in the DoS. | 21 | 7 |
| CAT 3 | Malicious Code | Successful installation of malicious software (e.g., virus, worm, Trojan horse, or other code-based malicious entity) that infects an operating system or application. | 344 | 76 |
| CAT 4 | Improper Use | A person violates acceptable computing use policies. | 173 | 8 |
| Total | | | 1,283 | 305 |

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. SHELLEY MOORE CAPITO TO
HON. JAMES F. BRIDENSTINE

Question 1. NASA's satellites and in-space telescopes are among the agency's most important assets. As we have discussed, I believe it is vital that we develop the technology to repair, refuel, and refurbish them, so that we can enhance their capabilities and operational lifetime. I am proud that the West Virginia Robotic Technology Center is advancing this technology through NASA's Restore-L program. Thank you for your support of this important work. How does NASA plan to ensure that Restore-L is able to conduct a flight demonstration in a timely fashion?

Answer. NASA agrees on the criticality of developing satellite servicing capabilities, but also recognizes that a transition is happening in the satellite business. Fast-moving technology and evolving customer demands are driving operators to rethink major investments in new satellites and consider other options such as obtaining a few more years of service out of their current platforms. As a result, satellite refueling and other in-orbit services market are estimated to possibly reach \$3B over the next decade. While NASA sees substantial value in satellite servicing capabilities, there are already significant investments from industry and another government agency to develop commercial satellite servicing capabilities. Therefore, the Agency has proposed an alternative approach to enable a flight demonstration of satellite servicing technologies by leveraging commercial interests and developing capabilities in a cost-effective manner. In this proposal, NASA would continue development of the critical satellite servicing technologies to TRL 6, while pursuing public-private partnerships with industry where commercial partners would propose which technologies in development they would demonstrate on their spacecraft based on their business plans.

Given the FY 2018 Omnibus Appropriations provided \$130M for a Restore-L mission, the Restore-L project worked on detailed system and subsystem design in FY 2018. The Restore-L team has completed mission, payload and spacecraft preliminary design reviews. The Restore-L Life Cycle Cost (LCC) range at KDP-B was \$629M to \$756M. However, current estimates put the budget profile for a full flight demonstration at approximately \$1B. This LCC would be 3–8 times the cost of any other NASA Technology Demonstration Mission project with LCCs that typically range from \$100–\$300M, and is not executable within the Exploration Technology budget without significant impact to technology priorities needed for the National Exploration Campaign. In lieu of a flight demonstration, it would be more cost effective to conduct ground development of the satellite servicing technologies that are of most interest to industry partners and leverage Technology Transfer mechanisms and pursue partnerships with interested U.S. companies as well as could potentially support lunar exploration efforts.

NASA believes the most cost effective approach is to utilize our technical expertise to develop these key technologies, while leveraging the strong commercial interest to enable a flight demonstration. This will provide a clear path to transferring the technologies to industry for multiple applications. As such, under the FY 2019 Budget request, NASA is proposing to refocus the Restore-L project toward technology development to TRL 6 with industry partners proposing which robotics systems and tools they would flight demonstrate on their spacecraft based on their industry business plans. Goddard Space Flight Center's Restore-L team, including their robotics partner West Virginia University, would continue to play a critical role in developing these capabilities. This approach is sustainable within the budget profile, and enables a broader technology demonstration portfolio aligned with exploration priorities. Servicing capabilities will also be demonstrated through DARPA's Robotic Servicing of Geosynchronous Satellites, using a public private partnership approach. The FY 2019 President's Budget Request recommends the advancement of satellite servicing technologies at \$45.3M.

Question 2. You mention in your testimony that the International Space Station (ISS) can help enable the transition the use of low-earth orbit (LEO) to commercial companies. What should Congress keep in mind in order to spur competition in LEO (low earth orbit)?

Answer. NASA intends to transition from the current Government-dominated model of human space activities in LEO to a model where Government is only one customer for commercial services. Based on inputs from current ISS partners, commercial and other stakeholders, NASA will shape the plan for the transition of LEO activities from direct Government funding to commercial services and partnerships, with new, independent commercial platforms or a non-NASA operating model for some form or elements of the ISS by 2025. In addition, NASA will expand public-private partnerships to develop and demonstrate technologies and capabilities to enable new commercial space products and services. NASA recently awarded study

contracts to industry to investigate the best way to use the ISS to enable commercial industry to take a lead role in LEO, and *twelve companies* are providing studies. The portfolio of selected studies will include specific industry concepts detailing business plans and the viability of habitable platforms, using Station or separate free-flying structures.

NASA looks forward to working with Congressional stakeholders along with researchers, private industry, and our ISS International Partners on the future of the ISS and LEO, to ensure that the U.S. maintains our human spaceflight leadership in LEO while shifting Government resources and focus towards expanding human presence into the solar system and returning benefits to U.S. taxpayers. As an example of NASA's efforts in this area, the Agency has repeatedly submitted a legislative proposal regarding the retention of intellectual property rights by users of the ISS National Laboratory. The language clarifies the ownership of intellectual property resulting from commercial research projects on the ISS that are conducted under the auspices of the 501(c)(3) entity managing this research.

Question 3. In your testimony, you mention the numerous and important partnerships with researchers across academia, industry and within the Agency. What number, or percentage, of your partnerships are with Universities? Are there any hindrances—you have experienced—in partnering with Universities?

Answer. NASA considers its history of partnering with U.S. universities for transformative research and innovations in support of science, exploration and technology to be consistently successful. We would be challenged to identify any significant hindrance that could be applied comprehensively to this family of partnerships.

NASA partnerships with U.S. academic entities, which include universities, represent approximately 8 percent of the Agency's total portfolio of partnership agreements, or approximately 240 agreements. This data, tracked and maintained by NASA's Partnerships Office, includes NASA agreements with domestic entities executed under a number of partnering authorities available to the Agency, such as the National Aeronautics and Space Act Authority (51 U.S.C. § 20101) and the Federal Technology Transfer Act (15 U.S.C., § 3710a).

It is important to note that this response represents domestic "partnership agreements" as designated by NASA for the purpose of ongoing data collection. It does not include the broader categories of agreement instruments that NASA may enter into with universities, including contracts, grants, cooperative agreements, and those with international academic entities.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO
HON. JAMES F. BRIDENSTINE

Question 1. NASA's inspector general confirmed at a recent committee hearing that it's unlikely NASA will save much, if any, money if the agency transitions the International Space Station (ISS) to a commercial operator. Given the ongoing cost of research and transportation, the near-term contributions proposed by the administration to help fund development of commercial platforms and the enormous cost of disassembling and deorbiting the ISS, it appears that ending government funding for the ISS in 2024 as the administration has proposed could be the most expensive possible option. How much money does NASA actually plan to free up under the administration's plan and when would we see any savings?

Answer. Witness did not respond.

Human Exploration Plan: NASA recently delivered the Human Exploration Roadmap. The plan, delivered nine months later than required by the NASA Transition Reauthorization Act of 2017, is lacking in any new details, including those on how proposed lunar missions will advance the ultimate goal of missions to Mars. In fact, the report calls for a human lunar landing by 2029 and only mentions in passing the expectation of a landing on Mars sometime beyond the 2030s.

Question 1. What does NASA need to get to Mars in the 2030s?

Answer. Witness did not respond.

Question 2. We can't afford to sacrifice NASA's other critical priorities in science in technology, but given the budget increases the agency has gotten in the past couple years, what can NASA do to speed up human exploration plans?

Answer. Witness did not respond.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. EDWARD MARKEY TO
HON. JAMES F. BRIDENSTINE

Question 1. A consortium of non-profit foundations and organizations recently announced a \$4 billion initiative to harness technologies to enhance sustainability and mitigate the effects of climate change. How can NASA work with non-profits and commercial companies to coordinate research on climate change in areas such as hazardous weather events, food security and agriculture, and ocean health?

Answer. Witness did not respond.

Question 2. The planetary science community made Mars Sample Return its highest-priority large initiative in the last decadal survey, but progress on achieving returned samples has been relatively slow, due to the perceived cost of such a landed mission or series of missions. What steps is NASA taking to realize the goal of returned Martian samples?

Answer. Witness did not respond.

Question 3. The NASA Engineering & Safety Center (NESC) recently released a report about the potential hazards of Martian dust to human explorers and even robotic missions. How is NASA working to preempt and address some of the scientific and safety issues that Martian dust poses to mission success?

Answer. Witness did not respond.

Question 4. When external factors or scientific discoveries prompt a reassessment of decadal survey priorities, how can NASA work with the National Academies of Sciences, Engineering, and Medicine to allow and vet input from the scientific community on potential changes?

Answer. Witness did not respond.

Question 5. Is NASA planning on adopting sexual misconduct reporting guidelines for its awardees that mirror the National Science Foundation guidelines, including a requirement that grantees receiving funding from NASA submit to the agency any findings or determinations of sexual harassment and/or misconduct? If not, why not?

Answer. Witness did not respond.

Question 6. How is NASA working to improve its policies, procedures, and practices surrounding the travel approval process for Center employees to attend scientific and professional conferences, meetings, and workshops, in order to ensure that the current approval process does not cause undue delay and uncertainty when developing travel arrangements?

Answer. Witness did not respond.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. TOM UDALL TO
HON. JAMES F. BRIDENSTINE

Climate Change. In early October, the Intergovernmental Panel on Climate Change released a shocking and concerning report revealing that both human society and our planet will experience the serious consequences of climate change as soon as 2040—in just 12 short years.

Question 1. What is your interpretation of the current IPCC Report on “Global Warming of 1.5 degrees C”, and the call for an all hands on deck approach to address climate change?

Answer. Witness did not respond.

Question 2. What is NASA’s role in helping the U.S. reduce the dangerous impacts of climate change?

Answer. Witness did not respond.

Question 3. How would you address the arguments of outside entities—and those serving in the current Administration—who refute scientific research on climate change, including NASA’s own research findings?

Answer. Witness did not respond.

Severe Weather Forecasting. You have previously stated that: spending 30 times as much money on global warming research as on weather forecasting and warning is a gross misallocation of funds.

Question 1. In your opinion, do you believe that more funding is needed to improve the technologies required for severe weather forecasts?

Answer. Witness did not respond.

Question 2. What role does climate change research play in advancing our ability to better prepare for severe weather in the future?

Answer. Witness did not respond.

NASA Workforce and Activities in New Mexico. I am interested in working with you to support NASA's workforce and activities in New Mexico. NASA has a presence at White Sands Missile Range and we want to increase activity at that site. Many commercial companies are preparing to offer spaceflight services not only for tourism, but also for science and technology development. New Mexico's Spaceport America is one of the best places for this kind of activity.

Question 1. How do you see these platforms, many of which have already manifested payloads, fitting into NASA's overall mission? And, could these vehicles offer a viable opportunity to expand the agency's science and human spaceflight opportunities?

Answer. Witness did not respond.

Question 2. What is NASA's position on vertical launch and point-to-point launch?

Answer. Witness did not respond.

Private Space Companies. In light of private investors, like SpaceX, Blue Origin, Virgin Galactic, and Virgin Orbit investing in space technologies and pushing for space exploration:

Question 1. Where do you see NASA's role in space exploration?

Answer. Witness did not respond.

Question 2. Will commercial suborbital human flights either benefit or conflict with NASA's work? Does NASA have plans to leverage the work of these private companies in human space exploration?

Answer. Witness did not respond.

Question 3. Does NASA have current plans to get back into the business of human space exploration? Is there a desire to travel to Mars, and what do those research goals entail?

Answer. Witness did not respond.

2017 NASA Authorization. Congress passed the last NASA Authorization in 2017. This law continues to guide NASA as a multi-mission agency with a, "balanced and robust set of core missions in space science, space technology, aeronautics, human space flight and exploration, and education."

Question. What specific strategies are you going to use to execute NASA's multiple missions, which encompass not just human space flight but also initiatives such as space-based observations of the Earth?

Answer. Witness did not respond.

NASA Technology and Safety Regulations. In light of the recent booster malfunction during the launch of the Soyuz MS-10 space craft set for the International Space Station:

Question 1. What is your confidence in joint space programs?

Answer. Witness did not respond.

Question 2. The DOD is making a concerted effort to replace the RD-180 engine in space launch. Does NASA have plans to do the same? If so, what are the options NASA is exploring?

Answer. Witness did not respond.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
HON. JAMES F. BRIDENSTINE

Budget Constraints. During the hearing, Senator Cruz asked why we were able to get to the Moon in seven years in the 1960s, whereas now, we are not expected to return to the Moon for another twelve years. In your response, you stressed that our current mission is fundamentally different than that of the space race in the 1960s, but also explained that budget constraints on NASA are to blame for the slower pace.

Question 1. In your estimation, can NASA achieve its goal of returning to the Moon in twelve years with its current budget?

Answer. Witness did not respond.

Question 2. To what extent would Congress need to increase NASA's budget in order to expedite its return to the Moon?

Answer. Witness did not respond.

Question 3. How large of a budget increase would NASA need to match the overall level of productivity that NASA achieved during the space race?

Answer. Witness did not respond.

Question 4. What does the United States stand to lose by delaying our return to the Moon?

Answer. Witness did not respond.

Protecting Astronauts from Radiation. During the hearing, you testified that NASA is committed to sending humans to the Moon and to Mars and to developing cislunar space. In these pursuits, United States astronauts will be removed from the Earth's protective magnetic field and will be exposed to harmful levels of radiation. Additionally, these missions will expose them to potential extreme space weather events, such as a coronal mass ejections, and other hazards.

Question 1. What is NASA doing to protect astronauts from radiation on these missions?

Answer. Witness did not respond.

Question 2. How will NASA protect astronauts, both in deep space and in low earth orbit, from an extreme space weather event?

Answer. Witness did not respond.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO
HON. JAMES F. BRIDENSTINE

Question. As the discussion around ensuring American leadership in the space race continues, I'd like to ask you about one of the projects NASA is developing known as the Space Launch System. Designed to support deep space missions, the Space Launch System project was originally scheduled to have its first test launch last year, but that test was delayed and now is scheduled for the end of 2019. The Space Launch System project seems very promising, and it is a prime example of American ingenuity and engineering expertise. Some very talented people at companies in my own state of New Hampshire are part of this project. What will you do to make sure that the Space Launch System meets the December 2019 test launch goal?

Answer. Witness did not respond.

STEM Education and Outreach. At a recent hearing, I had the opportunity to ask Dr. Kelvin Droegemeier, the nominee for Director of the White House Office of Science and Technology Policy, about science, technology, engineering, and mathematics (STEM) education in the United States. The United States is not producing enough qualified STEM graduates to meet our needs. This is a well-known fact, and part of the problem is that women and people of color are not joining these fields at equitable rates—leaving behind a large portion of our talent and impacting our future workforce pipeline. I asked Dr. Droegemeier about how the Office of Science and Technology Policy would meet those challenges, and he gave me a thoughtful answer. But I'm also interested in how NASA is approaching this problem, especially given that the President has proposed eliminating NASA's Office of Education.

Question 1. What have you done to encourage STEM education in the face of an Administration that does not seem to treat that as a priority?

Answer. Witness did not respond.

Question 2. Should Dr. Droegemeier be confirmed, will you commit to working with the Office of Science and Technology Policy to build our STEM workforce and improve outreach to women and people of color?

Answer. Witness did not respond.