

**EXAMINING THE FUTURE OF THE INTERNATIONAL
SPACE STATION: ADMINISTRATION PERSPECTIVES**

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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MAY 16, 2018
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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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EXAMINING THE FUTURE OF THE INTERNATIONAL SPACE STATION: ADMINISTRATION PERSPECTIVES

WEDNESDAY, MAY 16, 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 2:36 p.m. in room SR-253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

Present: Senators Cruz presiding], Nelson, and Gardner.

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

Senator CRUZ. This hearing is called to order. Good afternoon. We'll ask for the senator from Colorado to stop being unruly.

[Laughter.]

Senator CRUZ. Welcome to our witnesses. Welcome, everyone.

The International Space Station is the largest and most complex habitable space-based research facility ever constructed by humanity. It's a marvel of engineering, and it's critically important to our national space program. For over 17 years, the ISS has provided the United States with continuous access to low Earth orbit which has been paramount to the success of NASA, our commercial partners, scientific research, and to human space exploration.

It's due to the significance of the ISS as a key component of our national space program that this Subcommittee led the effort that extended the operation of ISS to 2024 by enacting the bipartisan U.S. Commercial Space Launch Competitiveness Act in 2015, which Senator Nelson and I worked on hand in hand and which was signed into law by President Obama.

We then followed up on that effort by once again working in a bipartisan manner, me working closely once again with Senator Nelson, in enacting the NASA Transition Authorization Act of 2017 which was signed into law by President Trump and established the ISS Transition Principles. The purpose of the ISS Transition Principles was to create a step-wise approach to eventually transition from the ISS once there is the emergence of a proven and reliable commercial alternative.

Congress decided to take a step-wise approach due to the long history at NASA in which major programs like Constellation and the Space Shuttle had been eliminated prematurely. These deci-

sions have long-term repercussions at NASA, its work force, the local communities surrounding NASA Centers, and American taxpayers who face increased replacement costs for lost capabilities. Not only was it concerning when NASA failed to deliver the ISS Transition Report to Congress before December 1, 2017, as required by Federal law, but it was deeply troubling when reports leaked that some were pushing a proposal to end all Federal funding of ISS in 2025.

Congress was explicitly clear in making its long-term interest in ISS known in the NASA Transition Authorization Act of 2017. Federal statute required the transition plan to include cost estimates for extending operations of the ISS to 2024, to 2028, and to 2030. It also required an evaluation of the feasible and preferred service life of the ISS through at least 2028 as a unique scientific, commercial, and space exploration related facility. Nowhere in Federal statute is there a request from Congress seeking a hard deadline to end Federal support for ISS, to cross our fingers and hope for the best. We've seen that act play out too many times in our national space program and it's time we learn the lessons of history.

Prematurely canceling a program for political reasons costs jobs and wastes billions of dollars. We cannot afford to continue to pursue policies that have the consequence of creating gaps in capability, that send \$3.5 billion in taxpayer money to the Russian government, or to create a leadership vacuum in low Earth orbit that provides a window of opportunity for the Chinese to capitalize upon.

Let me be clear. As long as I am Chairman of this Subcommittee, the ISS will continue to have strong support and strong bipartisan support in the U.S. Congress. And as long as Article I of the Constitution remains intact, it will be Congress that is the final arbiter of how long the ISS receives Federal funding.

I'd now like to recognize the Ranking Member of the Full Committee, Senator Nelson.

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

Senator NELSON. Thank you, Mr. Chairman.

Indeed, what we have is \$100 billion or more invested in low Earth orbit. Ever since we started assembling the Space Station years ago, this incredible flying machine, the Space Shuttle, which was designed to carry components that would go up to low Earth orbit, be assembled, and we now have a structure on low Earth orbit that is as large as a football field from goalpost to goalpost, or 120 yards. That's how big it is. People don't realize how big it is.

People don't realize the research that is going on, not only with somebody like Mark Kelly's twin brother, Scott, that went up and lived for a year so we could study the long-term effects of weightlessness on the human body—because when we go to Mars, hopefully, we're not going to have to go with conventional technology that would take us 8 months. Because then you've got to land, stay on Mars until the planets realign, which could be as much as a year, and then come back. We're not ready for that. Hopefully, we're going to sprint with faster propulsion. But even so,

it's going to be long periods in weightlessness unless we create some kind of centrifugal force, like a revolving spacecraft that would give some effect of gravity.

But, nevertheless, we need to figure out all of this, and we've got this platform up there that cost north of \$100 billion. Abandoning this incredible orbiting laboratory when we are on the cusp of a new era of space exploration, would be irresponsible at best and probably disastrous.

It's pretty clear that the proposal to end the funding of ISS by 2025—that wasn't a NASA decision. That was an OMB decision, which, traditionally, has been the bane of NASA's existence because they've wanted to run the space program. So it was a political decision.

As far as this Committee is concerned—and I can tell you as far as this senator is concerned—that proposal is dead on arrival because, as Ted says, this is a bipartisan outfit and we're looking at this in a bipartisan fashion, and, indeed, this is where you bring together all the players, industry, academia, everybody except the White House's Office of Management and Budget. OMB is the one that then focuses on a random date and it's the wrong way to approach a transition from the ISS.

Now, one day, low Earth orbit is going to be filled with commercial space stations and other platforms used by NASA. In lunar orbit, there are going to be commercial platforms and there's also going to be a NASA platform. That NASA platform will be a means by which, ultimately, we go in what has been set by the President as a goal to go to Mars in the decade of the 2030s with humans. So it's going to be a combination of government and non-government commercial activities.

But it's not fair to NASA or to industry to force a transition based on an arbitrary date. That decision should be based on factors like NASA's research requirements and the readiness of the industry to take the lead. We need to listen to our scientists and the experts at NASA. They have made it clear that NASA will continue to need access to low Earth orbit for astronaut training, technology development, and research.

So today, we have skilled people at Kennedy, at Johnson, indeed, across so many centers working on the ISS and on commercial crew and cargo, and these are some of the only people in the world who know how to keep people alive in space. If this plan to prematurely end the current ISS program moves forward, I fear that NASA's expertise in these critical areas, expertise that we're going to have to have if we're going to Mars with humans and safely return, will be lost.

The good news is that NASA's ISS transition report indicates that the Space Station has plenty of operational time left, at least through the end of 2028 and probably beyond. We have time to continue the critical research taking place on the Station, to keep training astronauts to live and work in space as they prepare for those long duration missions, and to develop a robust commercial market in low Earth orbit.

NASA should be focused like a laser on getting commercial crew up and running right now so that American astronauts can once again be launching to the Station from the Cape. NASA ought to

be laser focused as it's getting ready within 2 years to launch the largest, most powerful rocket ever, the SLS. NASA shouldn't be off on these rabbit trails having to defend a Space Station that ought to be there.

Once Boeing and SpaceX are regularly transporting crew to the Station, it's going to enter into a golden era and we'll see just how valuable the research platform is. It makes good business sense to take full advantage of our investment on the ISS, just as it is common sense to maintain our Nation's leadership in space. Remember, I said just a minute ago, the largest rocket ever, a third more powerful than the Saturn V that took us to the moon, is right around the corner from its first test flight. We want to keep NASA focused on that.

The ISS is an unprecedented accomplishment that continues to serve humanity and maintain U.S. global leadership in space. So I look forward for this Committee continuing to exercise its jurisdiction over this issue.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Nelson.

I would note there are issues on which Senator Nelson and I disagree, but on this issue, the importance of the ISS and a resolved commitment to not wasting the billions of dollars we have invested in that asset, Senator Nelson and I are on exactly the same page.

Now, I welcome each of the witnesses to present your testimony.

Senator NELSON. Why couldn't we agree on a lot of other pages? [Laughter.]

Senator CRUZ. We've got hours left in the afternoon.

Our first witness is Mr. Bill Gerstenmaier, who serves as the Associate Administrator for Human Exploration and Operations at NASA. Our second witness is Mr. Paul Martin, who serves as the Inspector General at NASA.

Now I'll recognize Mr. Gerstenmaier to present your testimony.

STATEMENT OF WILLIAM H. GERSTENMAIER, ASSOCIATE ADMINISTRATOR, HUMAN EXPLORATION AND OPERATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. GERSTENMAIER. Thank you very much for allowing me to present in this important hearing on Examining the Future of ISS: Administration Perspectives.

The ISS has accomplished amazing things and transformed the way that we see human space flight. Crews have lived continuously on ISS for almost 18 years. The ISS has enabled groundbreaking research that benefits us all. The Space Station has helped NASA prepare for deep space missions. The Space Station has allowed us to maintain a leadership role in international space flight.

The Space Station International Partnership has developed voluntary standards, such as the international docking standard, that could transform space flight for decades to come. These standards will allow anyone to be part of space flight by designing to these standards. The cooperation of the ISS partners is amazing and serves as an example of a diverse community working together for common goals.

Last, the ISS has enabled innovative U.S. companies to reinvent the launch industry. Further, crew—private sector developed crew

transportation systems with the aid of NASA are about ready to go fly.

With all these amazing accomplishments from the ISS, it is only fitting that we take time to seriously plan for the transition of ISS in low Earth orbit. NASA is preparing to secure the Nation's long-term presence in LEO by partnering with industry to develop commercial orbital platforms and capabilities that the private sector and NASA can utilize after cessation of direct U.S. Federal funding for the ISS by 2025.

To be clear, NASA is not abandoning low Earth orbit. We must ensure the right pieces are in place to maintain an operational human presence in low Earth orbit, whether through a modified ISS program, commercial platforms, or some combination of both.

We are asking industry, academia, and others through a series of funded studies to provide ideas for utilizing the unique properties of space and creating commercial opportunities.

We will work with the Space Council and the Department of Commerce to help with the transformation of low Earth orbit. We have also proposed funds in the 2019 budget that help support this transition.

NASA looks forward to working with Congress, stakeholders, other government agencies, researchers, private industry, and our international partners on the future of ISS and low Earth orbit to ensure that the U.S. maintains our human space flight leadership.

Thank you.

[The prepared statement of Mr. Gerstenmaier follows:]

PREPARED STATEMENT OF WILLIAM H. GERSTENMAIER, ASSOCIATE ADMINISTRATOR,
HUMAN EXPLORATION AND OPERATIONS, NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the future of the International Space Station (ISS) and NASA's long-term vision for use of low-Earth orbit (LEO).

NASA is preparing to secure the Nation's long-term presence in LEO by partnering with industry to develop commercial orbital platforms, and capabilities that the private sector and NASA can utilize after the cessation of direct U.S. Federal funding for ISS by 2025.

To be clear, NASA is not abandoning LEO. We must ensure the right pieces are in place to maintain an operational human presence in LEO, whether through a modified ISS program, commercial platforms, or some combination of both.

In October of last year, the members of the National Space Council endorsed a recommendation to the President that NASA should return to the Moon. Following that recommendation, on December 11, 2017, the President signed Space Policy Directive 1 which requires NASA to "*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.*" This was nearly 45 years to the moment since the last time that NASA landed humans on the Moon.

NASA will shift the focus of its human exploration program to the Moon and cislunar region with an eye towards Mars, evaluating new habitat technologies, surface transportation systems, landing systems, fuel generation, and storage solutions. In every domain, we intend to renew and strengthen our commitment to American commercial space companies, which are critical partners in the human exploration of the Moon, Mars, and beyond. As NASA reorients the human spaceflight program back to the Moon and beyond to Mars, we will push to develop new ways of operating in LEO that will benefit our exploration endeavors, science goals, and ultimately the taxpayers.

As you know, the ISS currently serves as a unique platform to prepare for human exploration beyond LEO, promotes U.S. economic activity in space, and accelerates innovative research and technology development. Equally important, under the lead-

ership of the United States, the ISS contributes to America's preeminence around the world in space and technological innovation. Since its inception over 30 years ago, the ISS partnership has been a model of peaceful international cooperation. ISS has exceeded all of its original goals and accomplished many things that were never envisioned. Things like helping to establish a cube satellite market and helping to return commercial satellite launches to the U.S. through reduced launch costs. However, NASA must look beyond ISS in its current form in order to continue U.S. leadership in LEO; that is why the NASA Transition Authorization Act of 2017, together with the Administration, are united in transitioning NASA's LEO activities to a model where NASA is one of many customers of a vibrant, U.S.-led, commercial LEO enterprise. The synergy between industry and Government requirements in this endeavor cannot be overstated. We are partners in ensuring American preeminence as the world's leading spacefaring nation.

The Administration views public-private partnerships as the foundation of future U.S. civilian space efforts, and NASA is continuing to develop cooperation on use of the Station to enable increased commercial investment and to transition to more public-private partnership models. For example, the Agency has begun to transition from a model where NASA provides payload integration and other services to one where those services can be purchased from many commercial partners.

As we consider the future of the ISS and U.S. leadership in space, it is helpful to review the benefits provided by U.S. leadership in LEO to exploration, space commercialization, and terrestrial applications.

Preparing for Human Deep Space Missions

In order to prepare for human expeditions into deep space, the Agency must first conduct breakthrough research and test the advanced technology necessary to keep crews safe and productive on long-duration space exploration missions. On-orbit platforms are necessary to mitigate 22 of the 33 human health risks in the portfolio identified by NASA's Human Research Program in support of current and future deep space missions. The research to mitigate these risks must continue beyond 2025 to ensure that we learn what is necessary to travel deeper into space and to live and work in microgravity for long durations. This requirement will not go away no matter what orbital platforms are used.

NASA also plans to continue to use LEO facilities as testbeds to fill critical gaps in technologies that will be needed for long-duration deep space missions. For example, elements of the ISS life support and other habitation systems will be evolved into the systems that will be used for deep space exploration missions and undergo long-duration testing. It is NASA's plan to first develop and demonstrate many critical technology capabilities using LEO platforms prior to deploying these capabilities beyond LEO. This approach is much more cost-effective and faster than conducting this research in cislunar space because of the risks inherent in operating so far from the Earth.

As both research and technology development requirements evolve, NASA will look to take advantage of additional platforms in LEO as a way to accelerate development timetables. If there are cheaper and more efficient ways to meet these requirements, NASA is prepared to utilize them.

Enabling a LEO Commercial Market

NASA's vision for LEO is a sustained U.S. commercial human spaceflight marketplace where NASA is one of many customers. We envision multiple privately-owned/operated platforms—human-tended, permanently-crewed, or robotic—together with transportation capabilities for crew and cargo that enable a variety of activities in LEO, where those platforms and capabilities are sustained to a greater degree than today by commercial revenue. These future platforms may either leverage ISS or be free-flying. This flexibility allows the private sector to determine how best to meet the market demand rather than have the Government dictate how to meet this demand.

NASA must also communicate our forecasted needs in LEO to allow the private sector to anticipate that demand in their business cases. The Administration has proposed 2025 as the date by which direct Federal support of ISS will end; setting this date provides market clarity for our commercial LEO supply partners. At the last National Space Council meeting at Kennedy Space Center, the Vice President asked the NASA Administrator to work with the secretaries of State and Commerce to develop a strategy for how we can further enable cooperation with our international and private industry partners to continue to develop the infrastructure and policies necessary to spur economic growth in space. That work is ongoing and we plan to deliver some of those recommendations at the fall meeting of the Council.

In this vision, NASA would be able to share the cost of LEO platforms with other commercial, Government, and international users. This would allow NASA to maximize its resources toward missions beyond LEO, while still having the ability to utilize LEO for its ongoing needs for research, training, and technology development.

In order to enable this vision, NASA is not only executing several public-private partnerships, currently centered around the ISS, to foster the development of customers for LEO capabilities, but also is maturing the supply industry to be able to meet future demands. NASA is also initiating the Commercial LEO Development program to further the development of commercial on-orbit capabilities beyond what is available today through the ISS.

The Commercial Resupply Services (CRS) contracts, the Commercial Crew Program, and the ISS National Laboratory are key complementary activities to enable this vision. Under the CRS contracts, NASA's two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK, have demonstrated not only the ability to provide cargo deliveries to ISS, but also the flexibility to recover effectively from mishaps. The addition of the Sierra Nevada Corporation as a third commercial service provider will add significant on-orbit and return capability. Both Orbital ATK and Sierra Nevada Corporation have begun to investigate options to perform significant on-orbit operations after their primary cargo mission is completed. These two providers are able to provide an on-orbit research capability independent of ISS. NASA's commercial crew partners, SpaceX and the Boeing Company, are developing the Crew Dragon and CST-100 Starliner spacecraft, respectively. These companies have made significant progress toward returning crew launches to the U.S., and NASA anticipates having these capabilities in place by 2019 to regularly fly astronauts safely to and from ISS. The crew and cargo vehicles, as well as the launch vehicles developed by these providers, have the potential to support future commercial enterprises as well as ISS.

The Center for the Advancement of Science In Space (CASIS) manages the activities of the ISS National Laboratory to increase the utilization of the ISS by other Federal entities and the private sector. CASIS works to ensure that the Station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological, and industrial communities. The ISS National Laboratory is helping to establish and demonstrate the market for research, technology demonstration, and other activities in LEO beyond the requirements of NASA. Commercial implementation partners are now bringing their own customers to LEO through the National Laboratory, as well.

ISS Transition

In the NASA Transition Authorization Act of 2017, Congress requested a plan from NASA to transition ISS from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a LEO non-Governmental human spaceflight enterprise. NASA has been building a strategy and assessing options that support this vision for the future of human spaceflight in LEO, and this is reflected in the ISS Transition Report, delivered to Congress in late March of this year. NASA anticipates that the ISS is capable of continuing to operate within prudent technical margins and its lifetime could exceed original engineering estimates. This is a testament to American ingenuity and technological prowess.

However, complacency is the enemy of progress in technology development. We must continue to push the boundaries of what we believe is possible, not just for NASA but for the entire space industry. NASA is ready to ensure that LEO is open for American business and that our international partners have a role to play in lunar development. The development of commercial space operations in LEO will benefit NASA as we continue to utilize those capabilities to do the things that only NASA can do in exploration. Those principals are two sides of the same coin—they operate together and are not mutually exclusive.

As we contemplate what will happen in this transition, it is important that we remember lessons learned from the ISS and continue to build on them for the next phase of NASA's involvement in LEO and beyond. This transition is an opportunity to demonstrate to the world that U.S. leadership in space is not about one program, but about the qualities that make us the greatest spacefaring nation on the planet. Our insistence that the industry has the ability to respond to Government imperatives and that our international partners can count on us to lead the next generation of capabilities in LEO and beyond will light the way for this next phase of human exploration.

ISS Transition Principles

Several key principles will be reflected in any strategy or decision regarding the ISS and the future of LEO, as well as NASA's role as one of many customers of services or capabilities that are provided by private industry as part of a broader commercial market. The following principles will ensure uninterrupted access to LEO capabilities and long-term national interests in human space exploration, while supporting national security objectives, such as a competitive industrial base and U.S. leadership:

- Expanding U.S. human spaceflight leadership in LEO and deep space exploration, including continuity of the relationships with our current ISS international partners;
- Increasing platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs;
- Spurring vibrant commercial activity in LEO;
- Continuing to return benefits to humanity through Government-sponsored basic and applied on-orbit research;
- Providing continuity among NASA's LEO, deep space exploration, and development and research activities and missions toward expanding human presence into the solar system;
- Maintaining critical human spaceflight knowledge and expertise within the Government in areas such as astronaut health and performance, life support, safety, and critical operational ground and crew experience;
- Continuing Government-sponsored access to LEO research facilities that enable other Government agencies, academia, and private industry to increase U.S. industrial competitiveness and provide goods and services to U.S. citizens; and
- Continuing to reduce the Government's long-term costs through private industry partnerships and competitive acquisition strategies.

ISS Transition Strategy

As part of a cohesive exploration strategy, NASA intends to meet its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness that could offer the prospect of lower cost to the U.S. Government, while at the same time expanding the economic sphere of U.S. industry into LEO and beyond. This could enable NASA to apply more personnel and budget resources to expanding human space exploration beyond LEO and enhancing U.S. leadership in human spaceflight around the world. Beyond the prospect of lower operational costs for a LEO platform, shifting focus to industry can additionally reduce the infrastructure burden on NASA, which could reduce operations and maintenance costs.

In order to ensure that private industry is prepared to provide the services and capabilities that support NASA's needs in LEO, as outlined in the key principles above, and to enable private industry to develop markets and customers beyond the Government, NASA is proposing the following approach:

1. Begin a step-wise transition of LEO human spaceflight operations from a Government-directed activity to a model where private industry is responsible for how to meet and execute NASA's requirements. Consistent with the *ISS Transition Principles*, this does not mean NASA is "commercializing the ISS." Instead, NASA maintains U.S. Government leadership and responsibilities as outlined in the Partnership agreements, and continues to maintain the essential elements of human spaceflight, such as astronaut safety and the high-risk exploration systems.

This will give NASA time to engage with industry to begin transforming the many NASA-directed activities that are currently performed through several contracts into more of a public-private partnership and/or services contract(s) model where NASA's current responsibilities are executed and managed by private industry. This time period will also provide the opportunity for NASA and private industry to engage with stakeholders and to only proceed when industry has matured and is capable of executing NASA's requirements. The transition of ISS will ensure that there are private companies with the experience and expertise to operate various types of platforms in LEO by the mid-2020s. This transition to private industry must be done in a cost-effective manner and not exceed current operational costs.

Consistent with the *ISS Transition Principles*, NASA will continue discussions with the ISS international partners to help shape the long-term future of LEO.

2. Solicit information from industry on the development and operations of private on-orbit modules and/or platforms and other capabilities that NASA could utilize to meet its long-term LEO requirements that are consistent with the *ISS Transition Principles*. The scope of the solicitation may include risk reduction development activities, or modules or elements that could either be attached to the ISS or be free-flying. The solicitation may also include private-industry-conducted studies on the future of the ISS platform that may be combined with private industry objectives in LEO.

NASA began with a solicitation in FY 2018 to gather broad industry input on interest in meeting NASA's long-term needs and objectives that should lead to multiple awards in FY 2019 funded out of the Commercial LEO Development program.

3. NASA will also be working with the Department of Commerce to investigate opportunities to facilitate and enable private industry to develop new market opportunities in LEO. It is important that U.S. industry discover the global competitive advantage of utilizing space for research and revenue-generation activities. This ultimately allows NASA to be one of many customers.

ISS Considerations and the Eventual Future of the ISS Platform

From a structural integrity analysis standpoint, the ISS platform is expected to have significant structural life well beyond 2028 (based on the current assessment period). Many of the ISS modules, particularly the modules launched in the later years of ISS assembly, are likely to have structural life well into the 2030s. Although it is thus likely technically feasible to continue to operate the ISS well beyond 2028 with continued maintenance, it is also necessary to consider the current high costs of operating this complex facility. The ISS lifetime must also be considered in the context of what our national priorities are for a robust LEO economy. The LEO economy is unlikely to reach its full potential if the Federal Government is the sole supplier of LEO research capabilities.

The future of the ISS will be evaluated using the *ISS Transition Principles* to ensure there is no gap in the availability of a LEO platform to meet NASA's needs, whether this means transitioning the operations of the ISS to private industry through public-private partnership, augmenting the ISS with privately developed modules, combining portions of the ISS with a new private platform, or de-orbiting the ISS and beginning anew with a free-flying platform.

Decisions about the future of the ISS will be discussed across the ISS international partnership. The partners agree on common themes for considering the future of ISS and exploration, including:

- Reducing operational costs;
- Offering frequent visible national astronaut opportunities;
- Continuation and continuity of research and technology development activities;
- Building synergies between LEO and exploration activities; and
- Support of commercial opportunities.

NASA's Long-Term LEO Requirements

NASA and the U.S. have a long history of human spaceflight leadership and LEO research and technology development that go all the way back to the Mercury program through Gemini, Apollo, Skylab, the Space Shuttle, and the ISS.

Regardless of what happens next in this transition, NASA will maintain U.S. leadership in LEO and human spaceflight through lunar exploration as a basis for gaining the knowledge and capabilities for Mars consistent with the *ISS Transition Principles*. Within that context, NASA is planning to continue with the following LEO needs and objectives beyond the life of ISS:

- Maintaining the current ISS international partnership and possibly adding new international and domestic participants;
- Conducting regular LEO crewed operations, including short-and long-duration missions:
 - Enabling operational space proficiency;
 - Shifting from human health and performance countermeasures development (the ISS portion of which is expected to be complete by 2024) to validations of integrated long-duration systems, habitation, operations, and crew isolation;
- Developing and demonstrating long-term technology/systems (*e.g.*, life support);

- Conducting space life and physical sciences basic and applied research at current level and capabilities;
- Conducting National-Laboratory-based research and technology development; and
- Providing opportunities for astrophysics, space, and Earth Science research.

These long-term requirements, while similar to that of the current ISS Program, could be met with various types of modules or platforms that do not necessitate a vehicle (or vehicles) as complex as the ISS. Many of the research activities could be conducted on shorter-duration platforms, similar to the Space Shuttle, or even crew-tended platforms.

Fast Forwarding to the Mid-2020s

Continuing with current policies, including the Commercial LEO Development program, NASA can project what the LEO landscape may look like in the mid-2020s. We will maintain our strong global leadership position in LEO, starting with the continuation of the ISS through 2024, the validation of commercial cargo and crew transportation costs, and the completion of many NASA exploration-related human and systems research and demonstration activities. Through the commercial LEO development program, we hope to have in operation multiple alternatives to the current model of space station operations that can both meet growing commercial needs and meet Government needs at a lower total cost to the Government than exists today.

Conclusion

NASA looks forward to working with Congressional stakeholders, 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.

Mr. Chairman, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.

Senator CRUZ. Thank you, Mr. Gerstenmaier.
Mr. Martin.

**STATEMENT OF HON. PAUL K. MARTIN, INSPECTOR GENERAL,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Mr. MARTIN. Thank you, Chairman Cruz, Senator Nelson, and thank you for the opportunity to discuss the future of the International Space Station.

Over the past 5 years, the Office of Inspector General has issued 13 reports related to the ISS, including reviews on NASA's efforts to maximize onboard research, manage contracts with private companies to fly cargo and crew, and maintain international partnerships that fund almost one-quarter of the Station's annual expenses.

My testimony today is informed by these past reviews, but draws primarily on findings from a forthcoming OIG audit that assesses NASA's progress in maximizing utilization of the ISS to accomplish its human exploration objectives. This report, which we plan to publicly release in a few weeks, will also examine the challenges associated with continuing ISS operations after 2024, as well as the status of NASA's plans for the Station's eventual decommissioning and deorbit.

For the past 20 years, the ISS has served as a unique platform for humans to learn about living and working in space, but a platform that costs NASA between \$3 billion to \$4 billion annually or about half of its human space flight budget. The President's 2019 budget request proposes ending direct Federal funding of the ISS beginning in 2025, and a March report outlines NASA's plans to become one of many customers of a commercially operated station or other privately owned low Earth orbit platform. In my remarks

today, I offer three observations about the Administration's admittedly high-level plans for the ISS post-2024.

Observation One. Based on our work, we question whether a sufficient business case exists under which private companies can create a self-sustaining and profit-making business using the ISS independent of significant government funding. From our perspective, it is unlikely that a private entity or entities would assume the Station's annual operating costs currently projected at \$1.2 billion in 2024. Such a business case requires robust demand for commercial market activities. Candidly, the scant commercial interest shown in the Station over its nearly 20 years of operation give us pause about the agency's current plans.

Observation Two. The amount of savings NASA may realize through commercialization of the ISS may be less than expected given the significant expenditures—particularly for crew and cargo transportation for NASA-sponsored flights to LEO coupled with ongoing civil servant and infrastructure costs—are expected to continue past 2025, even if many activities transition to a privatized ISS or another commercial platform. Consequently, any assumption that ending direct Federal funding frees up \$3 billion to \$4 billion beginning in 2025 to use on other NASA exploration initiatives is wishful thinking.

That said, unless the agency receives a substantial increase in funding or can dramatically reduce costs, it will be hard pressed to continue supporting ISS operations under its current model while attempting to fund other initiatives such as the Lunar Gateway, a lunar orbit and moon landing, and a crewed Mars mission.

Observation Three. One obvious alternative is to extend ISS operations under the current regime, which from a technical standpoint is doable, given that the Station's infrastructure and critical equipment are or soon will be certified to at least 2028. Our recent audit work determined that research for at least six of 20 top human health risks that require the ISS for testing and four of 40 technology gaps will not be completed by the end of 2024.

In addition, research into two other human health risks and 17 technology gaps are not scheduled to be completed until sometime in 2024, meaning that even minor schedule slippages could push their completion past the Station's planned retirement date.

Finally, at some future point, whether in an emergency or because its useful life has ended, NASA likely will need to decommision and deorbit most or all of the Station. NASA estimates a controlled re-entry of the ISS will take up to 3 years to execute and cost approximately \$950 million. However, NASA has not finalized such a plan or developed the necessary capabilities to safely deorbit the Station in an emergency.

In whatever time remains, NASA must redouble its efforts to maximize the Station's potential, and the sooner Congress and the Administration agree on a path forward for the ISS, the better NASA will be able to plan.

Thank you.

[The prepared statement of Mr. Martin follows.]

PREPARED STATEMENT OF HON. PAUL K. MARTIN, INSPECTOR GENERAL,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Chairman Cruz, Ranking Member Markey, and Members of the Subcommittee:

The Office of Inspector General (OIG) is committed to providing independent, aggressive, and objective oversight of NASA, and we welcome this opportunity to discuss the Agency's utilization of the International Space Station (ISS or Station) and the challenges and opportunities related to its post-2024 future.¹

The OIG has issued 13 reports related to the ISS over the past 5 years, including reviews on NASA's efforts to maximize research, extend its operations, manage contracts with private companies to fly cargo and eventually crew to the Station, and maintain international partnerships that fund close to one-quarter of the Station's annual expenses. My testimony today is informed by these past reports, but primarily draws on findings in a forthcoming audit assessing NASA's progress in maximizing utilization of the ISS to accomplish its human exploration objectives. This report—which we plan to release publicly in the next few weeks—will also examine the options and challenges associated with the Station's eventual retirement and deorbit.

For the past 20 years, the ISS has served as a platform for humans to learn about living and working in space. NASA's original vision was that astronauts living on the Station would conduct biological and materials research, demonstrate American leadership in space, forge international cooperation, and lead efforts to commercialize low Earth orbit. To date, the Agency has accomplished many of these goals. NASA has sponsored research aboard the ISS in the areas of life and physical sciences, human health, astrophysics, Earth sciences, space science, and commercial research and development for pharmaceuticals, materials, manufacturing, and consumer products. The ISS has also been used in disaster response on Earth by providing near-real time mapping support for recovery and humanitarian aid efforts. However, all of these achievements have come at a cost of \$3–\$4 billion annually or about half of NASA's annual human space flight budget.²

Against this backdrop, the President's Fiscal Year (FY) 2019 budget request proposes ending direct Federal funding of the ISS beginning in 2025, and a congressionally mandated report prepared by NASA and submitted in late March provides a high-level outline of the Agency's plan to transition the Station to commercial operation. Our forthcoming report examines this plan as well as other options the Agency may consider, including extending ISS operations beyond the current retirement date and the necessity at some future point to safely dispose of the Station through a controlled destructive re-entry into the Earth's atmosphere.

Transition to Private Operations

NASA's current plan for the future of the ISS past 2024 is to transition responsibility for its operation—in whole or in part—to a commercial entity or entities. The Agency expects this approach to offset some portion of its substantial annual investment in ISS operations while providing more cost-effective operation of the Station through increased private sector investment, ultimately spurring greater commercial development of low Earth orbit. Under this plan, NASA envisions itself as only one of many customers for the ISS or other privately-owned and operated low Earth orbit platforms.

As part of this vision, the Agency is considering a range of options including transitioning operations to private industry, augmenting the Station with privately developed modules, combining portions of the current platform with a new private platform, or deploying an entirely new free-flying platform and de-orbiting the ISS. NASA is also assessing whether its long-term research requirements, while similar to those of the current ISS Program, could be met with platforms or modules that do not require a vehicle as complex and expensive as the ISS.

NASA has taken several concrete steps over the past 10 years to meet its goal of increasing commercialization of the ISS and low Earth orbit. Most prominently, NASA pays commercial partners Orbital ATK and Space Exploration Technologies Corporation (SpaceX) to deliver cargo to the ISS with a third contractor, the Sierra Nevada Corporation, scheduled to begin resupply flights in 2020.³ In addition,

¹The ISS is currently authorized to continue operations until October 1, 2024.

²In FY 2018, the ISS budget included approximately \$1.7 billion for crew and cargo transportation, \$1 billion for systems operations and maintenance, \$267 million for research, and \$225 million for labor and travel.

³Through its first round of Commercial Resupply Services contracts (CRS-1), NASA awarded a total of 31 cargo resupply missions to Orbital ATK and SpaceX worth \$5.9 billion, or an average cost of \$191.3 million per mission. As a follow-on to CRS-1, in 2016 NASA awarded a second

NASA is paying The Boeing Company (Boeing) and SpaceX to transport astronauts to the ISS as early as FY 2019. These activities represent NASA's most significant investment in the commercialization of low Earth orbit, given that cargo and crew transportation account for approximately \$1.7 billion or roughly 50 percent of the Station's annual costs.

NASA is also engaging private industry directly regarding potential future commercialization of the ISS. For example, in July 2016 NASA issued a Request for Information seeking industry ideas to stimulate economic development through the use of unique ISS capabilities. Last month, NASA released a Research Announcement soliciting industry concepts, business plans, and viability studies for development of commercial platforms in low Earth orbit, as well as industry input on the role Government should play in the commercialization of low Earth orbit. NASA also plans to coordinate with the Departments of Commerce and Transportation to create a multi-agency working group to identify specific actions or legislation that would enhance development of a commercial market in low Earth orbit.

While all of these actions are positive steps, NASA's current plan to privatize the ISS remains a controversial and highly debatable proposition, particularly with regard to the feasibility of fostering increased commercial activity in low Earth orbit. Specifically, it is questionable whether a sufficient business case exists under which private companies can create a self-sustaining and profit-making business independent of significant Government funding. In particular, it is unlikely that a private entity or entities would assume the Station's annual operating costs, currently projected at \$1.2 billion in 2024. Such a business case requires robust demand for commercial market activities such as space tourism, satellite servicing, manufacturing of goods, and research and development, all of which have yet to materialize.

Candidly, the scant commercial interest shown in the Station over its nearly 20 years of operation gives us pause about the Agency's current plan. This concern is illustrated by NASA's limited success in stimulating non-NASA activity aboard the Station through the Center for the Advancement of Science in Space, Inc. (CASIS). Established in 2011 to facilitate use of the ISS by commercial companies, academia, and other Government and non-Government actors for their research or commercial purposes, CASIS's efforts have fallen short of expectations. Apart from these privatization challenges, the amount of cost savings NASA may realize through commercialization of the ISS may be less than expected given that significant expenditures—particularly in crew and cargo transportation and civil servant costs—will likely continue even if many low Earth orbit activities transition to a privatized ISS or another commercial platform.

Extension and Continued Operations

An obvious alternative to privatization is to extend current ISS operations. NASA originally targeted the Station's service life to end in 2015, approximately 15 years from the time its first elements were placed into orbit. Since that time, NASA has extended the Station's operational life on two occasions: the first in 2011 when ISS construction was nearing completion (an extension through 2020) and the second in 2014 that approved continuation of ISS operations through 2024.

NASA is currently evaluating the feasibility of extending the Station's service life through at least 2028. As of June 2017, Boeing, NASA's prime ISS contractor, had certified all major U.S. structural elements to 2028 with the exception of an external stowage platform and six truss segments that it expects to certify by 2019. In addition, Boeing has assessed and cleared to 2028 critical operational capabilities such as electrical power, environmental control and life support, and thermal control.

An extension to 2028 or beyond would enable NASA to continue critical on-orbit research into human health risks and to demonstrate the technologies that will be required for future missions to the Moon or Mars. In recent audit work we determined that, as of February 2018, NASA forecast that research for at least 6 of 20 human health risks requiring the ISS for testing and 4 of 40 technology gaps will not be completed by the Station's planned retirement in September 2024. In addition, research into 2 other human health risks and 17 additional technology gaps is not scheduled to be completed until sometime in 2024, meaning that even minor schedule slippage could push completion past the Station's planned retirement date.

While NASA may be able to find alternative, ground-based testing options for certain health risks and technology demonstrations, Agency officials have stressed that research into others will continue to require the Station's unique microgravity environment. If the remaining health risks and technology demonstrations cannot be

round of resupply contracts known as CRS-2 to Orbital ATK, SpaceX, and the Sierra Nevada Corporation.

fully tested on the ISS, NASA may have to accept higher levels of risk than planned for future exploration missions.

Extending the ISS past 2024 presents NASA with multiple challenges, most pointedly its \$3–\$4 billion annual cost. Moreover, any extension could also increase the possibility of failure in the Station’s aging systems and infrastructure. Finally, continued support from NASA’s international partners—who currently pick up about 23 percent of the U.S. Segment’s operating costs—remains an open question beyond 2024.

Funding Issues

NASA currently spends about half of its Space Operations budget in support of ISS operations and will continue to do so with any extension of the ISS’s service life beyond 2024. Unless the Agency receives a substantial increase in funding or can dramatically reduce the cost of ISS operation and maintenance, NASA will be hard pressed to continue supporting ISS operations under its current model while attempting to fund its other potential space exploration initiatives such as the Lunar Orbital Platform-Gateway, a lunar orbit/landing mission, and preparations for a crewed Mars mission.

Even if the Agency ends direct funding of the ISS in 2025 as envisioned in the President’s FY 2019 budget request, it is unlikely that the bulk of the funding currently devoted to the ISS Program could be immediately diverted to these and other exploration activities. Even with termination of most Station activities, NASA expects to retain a presence in low Earth orbit and therefore would need to fund related crew and cargo transportation costs. Furthermore, significant funding would be required to maintain offices and infrastructure currently funded by the ISS Program such as the Mission Operations office, which is expected to be needed by future exploration programs.

Over the past 10 years, NASA has worked to reduce the costs of supporting the ISS, particularly crew and cargo services—the Program’s most expensive element. In addition, NASA has saved more than \$172 million annually since 2007 through de-scoping, renegotiating, and combining Station-related contracts. For example, NASA renegotiated the Program’s largest contract for engineering support with Boeing in 2010, reducing requirements and saving an estimated \$67 million per year. In addition, by combining its mission support, program integration, and infrastructure operations contracts, NASA estimates it has saved an average \$59 million per year since 2013. NASA also awarded a new contract in 2015 to support spaceflight operations, thereby reducing costs by an average \$46 million per year. While these are positive cost reductions, taken together they represent a small portion of the ISS Program’s overall budget.

Managing Risks of Hardware Failures

By 2028, the original elements of the Station will be 30 years old and will have operated for 3 decades in a harsh microgravity environment, exposed to ionizing radiation, extreme temperature changes, and micrometeoroids and orbital debris. While many systems have been replaced or upgraded and the Agency has not identified any structural issues that would preclude an extension through 2028, risks related to hardware degradation, system failure, and technological obsolescence may increase with continued operation beyond 2024. These issues have significant implications on NASA’s ability to repair or replace components because transportation of relatively large items is more difficult since retirement of the Space Shuttle, an issue NASA is taking steps to address.

According to NASA, micrometeoroids and orbital debris strikes are the primary threat to the Station’s integrity because a direct strike can cause catastrophic and irreversible depressurization or other significant damage with immediate life-threatening risks to the crew. To mitigate this risk, the U.S. Government currently tracks more than 500,000 pieces of man-made, orbital debris, which consists of nonfunctional spacecraft, abandoned launch vehicle stages, and other mission-related debris.

Continued Support of International Partners

Lastly, any discussion of whether to extend ISS operations past 2024 needs to consider the level of support from NASA’s current international partners—Russia, the European Space Agency (ESA), Canada, and Japan—whose continued participation hinges on issues ranging from international politics to differing space exploration goals. For example, the outlook for Russia’s continued involvement with the ISS is uncertain given the current state of relations between the two countries. Russia’s role is critical to sustaining Station operations because it controls the Station’s propulsion system and propellant and is currently the only partner capable of providing crew transportation to and from the ISS. The participation of NASA’s other current international partners is also unsettled at this time given their desire to

consider exploration missions beyond the ISS. For example, ESA has announced its intent to partner with NASA on the Lunar Orbital Platform-Gateway and other lunar activities. ESA is also working with the Chinese Space Agency to fly European astronauts on the Chinese space station planned for operation in 2022. Given that NASA's current international partners cover 23 percent of the Station's shared annual costs, the loss of one or more of these space agencies could have a significant impact on NASA's cost to extend ISS operations beyond 2024.

Decommission and Deorbit

At some point, whether in an emergency or because its useful life has ended, NASA will need to decommission and deorbit the Station. Ideally, this will occur via a controlled, destructive re-entry into the Earth's atmosphere. NASA estimates a controlled reentry of the ISS will take up to 3 years to execute and cost approximately \$950 million. However, the Agency has not completed the necessary tasks to execute such a deorbit. In January 2017, NASA completed a draft plan to address various deorbit scenarios; however, the plan has not been finalized and is pending review by the Russia Space Agency. And, while NASA engineers continue to work on the technical details of deorbit scenarios, the Agency presently does not have the capability to ensure a controlled deorbit of the ISS in the event of an emergency.

Conclusion

For the past 20 years, NASA has used the ISS as a research platform in low Earth orbit essential for advancing its deep space ambitions. But such celestial research comes at a steep cost: each year the Station remains in orbit, NASA allocates roughly half of its total human space flight budget to ISS operations—an expenditure that limits the Agency's ability to fund development of systems needed to work the moon and other destinations beyond low Earth orbit.

Each of the options for extending, transitioning, or retiring the ISS presents NASA with significant challenges that will require it to balance cost, feasibility, and risk. The President's FY 2019 budget request proposes ending direct Federal funding of the ISS by 2025, at which time NASA proposes transitioning the Station to commercial operations. While this proposal faces an uncertain future in Congress, we question whether a sufficient business case will exist by that time to make such an option feasible.

Similarly, NASA's other options present challenges. Extension of the ISS past 2024 will require significant ongoing funding, which would eat into the money available for NASA to pursue its other exploration goals. In addition, extending the ISS to 2028 or beyond would increase safety risks due to aging hardware and equipment. Moreover, it is unclear whether NASA can count on funding from its existing international partners if it seeks to extend the Station's operations beyond 2024. Finally, NASA needs to finalize a plan to decommission and safely deorbit all or part of the ISS at the end of its useful life.

Regardless of the outcome, NASA must redouble its efforts to maximize the potential of whatever time remains on the Station. Important work on several human health risks and technology demonstrations will not be completed by 2024, leaving NASA with the choice of extending Station operations, relying on alternate testing methods, or accepting higher levels of risk. The sooner Congress and the Administration decide on a path forward for the future of the ISS, the better NASA will be able to plan.

Senator CRUZ. Thank you, Mr. Martin. Thank you, gentlemen, for your testimony.

Mr. Gerstenmaier, where did the 2025 date to end Federal support for the ISS that's cited in both the ISS Transition Report and also the President's budget request—where did that date originate?

Mr. GERSTENMAIER. It originated in the Administration.

Senator CRUZ. Did it originate in OMB?

Mr. GERSTENMAIER. I don't know specifically where it came from, but it came from the Administration and discussions about picking a date collectively.

Senator CRUZ. So the date did not come from NASA?

Mr. GERSTENMAIER. We didn't pick a particular date. We talked about criteria, as you've seen in the Transition Report and other things. We didn't see the necessity of picking a specific date within

the agency, but as part of the Administration, we came to the conclusion that picking a date would prompt a serious discussion.

Senator CRUZ. The NASA Transition Authorization Act of 2017, as you know, required NASA to submit the ISS Transition Report to Congress not later than December 1, 2017. NASA was 3 months late in submitting that report, which was in direct contradiction to Federal law. How many drafts of the ISS Transition Report were prepared before the final report was submitted to Congress on March 30, 2018?

Mr. GERSTENMAIER. I don't have a specific number, but we go through a pretty iterative process of putting the report together with lots of comments from a variety of folks, so there were numerous iterations of the report placed together. I think part of the reason was the complexity of the report. If you look at the requirement language in the bill, there was a lot of information required, and we did our best to pull together all that data, and, frankly, we missed the December date on our own just because we couldn't get the information put together and written down in time to make that December date.

Senator CRUZ. Is it correct that NASA sent at least two drafts to the Administration, both of which were rejected?

Mr. GERSTENMAIER. I don't know. I'd have to go check on the specific number. I would say they'd never been rejected. They get sent over, and we get comments back. We iterate back and forth on the comments, and that occurred after the December deadline. It occurred this year.

Senator CRUZ. On February 20, 2018, Senator Nelson and I together sent a letter to NASA requesting, quote, "All preliminary versions of the ISS Transition Report as described in Public Law 115-10 including any drafts of the report that have been delivered to OMB or the National Space Council for review." To date, that request has not been complied with. Does NASA intend to comply with that request?

Mr. GERSTENMAIER. Let me take that question for the record, and we'll deliberate and see.

[The information referred to follows:]

Answer: The process of generating a report is an iterative one, both inside NASA and with the rest of the Administration. Thus, it is not the case that drafts are "rejected"—they are revised to reflect the wider policy context in which they are developed.

Answer: Draft reports are predecisional materials that reflect Executive Branch deliberations. They often contain initial views of individuals before other individuals have commented and further discussions occur. They are by nature preliminary and often do not reflect the ultimate view of the Administration or the Agency. Accordingly, their release creates a risk of impeding the free exchange of views and positions that is critical to effective decision-making.

Senator CRUZ. To your knowledge, is someone in the Administration specifically blocking NASA from providing those documents?

Mr. GERSTENMAIER. There's no specific blockage. I think we just need to discuss amongst ourselves what the benefit is and what's in those versions of the documents and see if they're helpful or not in the discussion moving forward. Many of the comments will reflect actual debates within NASA itself, where we had lots of discussions back and forth about what should be in the document, what shouldn't be in the document, et cetera. Some of those things

we consider somewhat pre-decisional, where we'd like to have that free debate within the agency.

We think it's important for us to have open dialogue within the agency where we can disagree with each other and not be subject to external review. So for some of those reasons, we'd like to hold some of those back. But I'd like to meet with our teams and the legal folks, and we'll get together and determine what the right approach is.

Senator CRUZ. Well, let me be clear. We're not asking for internal documents within NASA. We're asking for any drafts that were submitted to OMB. So, presumably, once a draft was submitted to OMB, NASA had resolved the internal questions and was submitting something for approval, and it is my concern that considerations other than the merits of the science drove this decision-making process.

So the letter from Senator Nelson and me was not a request for NASA to assess how helpful it might be or not to have those drafts submitted to OMB turned over to us. It is rather for Congress to make that determination.

Let me ask a different question on the merits. Mr. Gerstenmaier, as a scientific matter, is the ISS capable of operating beyond 2025?

Mr. GERSTENMAIER. Yes.

Senator CRUZ. How long do you believe we can safely operate the ISS?

Mr. GERSTENMAIER. We've done a look at the structural integrity and the major components through 2028, and it looks very viable through 2028. The current maintenance on Station is fairly low. We just did a space walk today to repair some things and move things forward, but that's predicted. I think we have a good operational life at least through 2028 and possibly a little bit further beyond that. We just need to continue to watch Station and continue to maintain it.

The IG calls out in their report components we need to watch and upgrade and maintain. But the teams are doing a good job of doing that and keeping it in good operational capability. What we don't want to have happen is where we're spending more time doing maintenance than we are doing research. At that point, then, the utility of Station starts to diminish, and we have not seen that yet. Station is very viable at least through 2028.

Senator CRUZ. Page six of the ISS Transition Report states, quote, "Among the benefits beyond the prospect of lower operational costs for an LEO platform, shifting focus to industry can additionally reduce the infrastructure burden on NASA, as has already been demonstrated at NASA facilities at Kennedy Space Center, Johnson Space Center, Stennis Space Center, and Michoud Assembly Facility."

If the policy as described in the ISS Transition Report is carried out, how will the infrastructure of the Johnson Space Center be reduced?

Mr. GERSTENMAIER. I think what the report is referring to is it's talking about a way we can reduce the infrastructure costs for NASA programs. So in the case of the Michoud Assembly Facility, we were able to bring some commercial companies in that could use the facilities at Michoud in parallel with our operations. So then

they would share some of the facility use, some of the utility bills, some of the support personnel. There were multiple users in the facility of which NASA only had to pay now a portion of some of that infrastructure cost. So that's what that report is referring to.

So when we think of Space Station, if we have multiple users in space, where NASA is just one of multiple users, then that cost of infrastructure and, say, cargo flights or crew flights—those can be shared between the government and the commercial sector, and then that lowers the cost to the government. That's what's implied by that infrastructure discussion. So it's not a reduction in personnel. It's an efficiency that's gained.

So at the Johnson Space Center, if some commercial companies could come in and do operations in the facility or in the center where they share some of the overhead of maintenance and lighting and utilities, then that lowers costs for NASA. So that was what the intent of that discussion was in the report.

Senator CRUZ. How would you project that Mission Control at JSC would be impacted?

Mr. GERSTENMAIER. Again, we see Mission Control continuing at JSC as we bring commercial crew online. Boeing has chosen to operate CST-100 out of the Johnson Space Center. We also see the Gateway activity that we do around the moon—that will be operated out of the Johnson Space Center. So I see Mission Control continuing into the future as we move human presence into the solar system, carrying the traditional role that the Johnson Space Center has carried in the past.

Senator CRUZ. So as I mentioned in my opening statement, NASA hasn't fared well in the past when decisions were made prematurely in major programs, like Constellation and the Space Shuttle. While there were a host of valid reasons for needing to transition away from the Space Shuttle, the reality is the program was phased out before an alternative was established. This decision created a gap in capability for our National Space Program and has made NASA reliant upon Russia to transport American astronauts to and from the ISS.

As you can see from this first chart here, between 2006 and 2018, the price that NASA has paid the Russian government to secure seats to transport American astronauts to and from the ISS has increased from roughly \$21 million to over \$80 million, a cost increase of 372 percent or a \$60 million increase in just 12 years.

As you can see from this second chart, the consequence of having this gap in capability means that American taxpayers will have sent roughly \$567 million to the Russian government to transport our astronauts to and from the ISS, which comes out to roughly \$3.5 billion between 2006 and 2018. And it's also worth noting that commercial delivery systems cost will be 2.4 times more than the Space Shuttle.

What do you see as the consequences in terms of capability lost if Federal funding is phased out for the ISS in 2025?

Mr. GERSTENMAIER. Again, I think, you know, we have some principles that we carry within human space flight, and one of those principles is the continuity of human space flight. We believe keeping a continuous presence in human space flight is important

and continuing to keep a leadership role in space flight, and I think Station needs to have that leadership role.

What we're describing here with this activity is we think now is the time to do the planning to make sure that we have a good transition from the predominantly government-funded Space Station we have today to where we have now commercial space stations and other activities in low Earth orbit that we can continue to use to keep our leadership role and to keep human presence in space. So we're thinking more of a transition rather than a stop and then a start. As you've shown through your graphs in the plots here, it's not good when you stop and then you start at some TBD point in space.

So what we're trying to do through this activity and through the Transition Report is establish some principles, which you can read in the report. We're trying to go out to industry, ask industry what the government can do to help them take a better role in low Earth orbit operations, and how we can make an effective transition where the government doesn't have to be the sole payer and U.S. industry can do new things in innovative ways in space.

We've seen some positive examples of that with both commercial crew and commercial cargo. I think there are some real advantages of the private sector doing some things in innovative and creative ways. I think we can do the same thing in low Earth orbit. We need some time to do that. We would like to begin that activity in earnest now, and then we can see how that works through the period of time and then figure out when the right time is to transition Station.

Senator CRUZ. So, as you know, China has announced that it intends to have its first permanent manned space station ready for service in 2022. Do you have any concerns that China may be putting itself in a position to fill a leadership vacuum in low Earth orbit if it's the only country with an operational station beyond 2025?

Mr. GERSTENMAIER. I think we need to be aware of that consideration and factor that into our planning as we go forward.

Senator CRUZ. Final question for Mr. Martin. Both the ISS Transition Report and the President's budget request list 2025 as the date on which direct Federal support of the ISS will end. Has your office looked into where that 2025 date originated, and, if not, will you commit to examining that question?

Mr. MARTIN. We have not looked into where the 2025—and, respectfully, we will not look into—it's a policy issue by the Administration. Unless there's some evidence of any nefarious outside influence on that decision, it really is a policy decision, much like the previous administration had decided to focus on an asteroid retrieval mission as opposed to a lunar return.

So, really, the Inspector General's Office—we look at—we don't deal with policy. We're not management. We look at programs once they've been decided on by the Congress and the Administration, and then we find fault in those programs.

Senator CRUZ. With all due respect, Mr. Martin, it is not a policy decision when it is directly contrary to Federal statute that has been enacted into law—the NASA Transition Authorization Act of

2017—and I believe that date directly contradicts statutory language that was passed unanimously by both houses of Congress.

Senator Nelson.

Senator NELSON. Thank you, Mr. Chairman. This Senator has been through a kabuki dance on the issue of OMB trying to control NASA for years and years. It's a problem in both Democrat and Republican administrations and here we go again.

Mr. Martin, I'm going to have most of my questions for you, because Mr. Gerstenmaier is in a very difficult position, as he has to mind the fact that there are those folks at OMB who think they're running NASA, so he has to be careful about what he says, even though he's one of the best NASA managers that has ever come down the pipe.

But I do want to ask Mr. Gerstenmaier—and I think it will make the point here—when Senator Kay Bailey Hutchison and I authored the NASA authorization bill of 2010 that set NASA off on the dual course of a commercial industry of launchers as well as NASA being able to get out beyond low Earth orbit and explore and, thus, the course that we are now seeing come to fruition with the launches of two commercial rockets carrying crew within the next year and then the big rocket as the first of the Mars program maybe in a couple of years, all of that set the table so that it would be worthwhile for commercial companies to come in and develop rockets and spacecraft in order to get humans to and from the International Space Station, which also would allow us to stop paying the Russians all of those monies that we've paid over the years, even though they've been a reliable partner.

So, given the fact that this was a business model for SpaceX, for Boeing, and others to come, to go to and from low Earth orbit, specifically the Space Station, what do you think this is going to do to their business model if suddenly there's not an International Space Station there?

Mr. GERSTENMAIER. It's envisioned in the way we've seen the legislation is that there would be potentially other commercial platforms in low Earth orbit that could be serviced by both of these companies, both by the cargo providers and also by the crew transportation providers. So the idea was instead of having a sole government space station, there would be a government station, potentially other smaller commercial space stations in low Earth orbit of which this industry, the supply industry of transportation, would be able to service.

So that's the discussion we've had, and that's the thing we're trying to pursue, to see if there's a market that supports that and to put the details of how that works. And we're going to ask industry and ask others through a series of studies here fairly soon to give us their business plans, to give us their understanding of what they see as the revenue potential in low Earth orbit.

I think we're starting to see a real interest in low Earth orbit from commercial companies, where there's just an inkling that there could be some revenue generation there. That's a starting point. That's a tipping point, and what we need to do is we need to figure out a way we can help enable that through the Commerce Department, through NASA, to get that vibrant economy there, and then again we'll see this commercial sector take activity in low

Earth orbit. So we have to walk between figuring out the right time for the government station to start ramping down and the private station to start coming in place.

Senator NELSON. And you do not have any assurance that that business model is still there to support their commercial rockets. Is that correct?

Mr. GERSTENMAIER. There's no absolute assurance that that business model is there. But we can construct a transition plan thoughtfully amongst all of us that can help lower the risk to acceptable levels where it's a right risk for the private sector and it's a right risk for the government to get the capabilities we need in low Earth orbit.

Senator NELSON. Mr. Martin, what was it that you were talking about—six of 20 human risks that requires research on the ISS? Six of 20 human risks, you say, have been identified on the Station.

Mr. MARTIN. Yes, sir. NASA has a very robust program to look at—from their Human Research Program to look at what are the key health and human performance risks that can be detrimental to astronauts in long-duration space flight, and they have a very colorful chart that maps out when they would get these risks to a successful point where they could either mitigate it or they've decided to accept the risks. And according to NASA's own figures, six of the 20—the mitigation activities and the research on those health and human performance risks will not be completed by 2024.

Senator NELSON. Mr. Gerstenmaier, do you think that substitutes, if they could be put up—commercial stations—by 2025 would be available? Do you think that's possible?

Mr. GERSTENMAIER. I think it's possible for those items, and what we need to do is make sure that those unique facilities and capabilities are present in the commercial activities, so we can actually make sure that they have the ability to investigate those particular areas.

Senator NELSON. You know, right now, NASA is paying for the transportation cost to and from the Station on commercial cargo and soon to be American astronauts to go to and from. Do you think that the commercial companies could pick up that burden if NASA were to abandon the ISS?

Mr. GERSTENMAIER. Again, I think, as we've all seen, one of the largest costs for having a capability in low Earth orbit is the transportation cost. So we need to watch that transportation cost. Again, I think the model is if there's revenue generation by the private sector, then they can pay for some portion of that transportation cost—and what that percentage is, I don't know, but we can work that out—and then the government gets a reduced cost for the activities that the government needs. So then the government pays for the services it requires and what it needs.

So there's a transition phase so it doesn't go from full government funding to no government funding. I think there needs to be a transition phase, and that's what we've kind of alluded to in the Transition Report of how we discover and how we build that right transition model to make sure we don't lose this capability that we've acquired with Space Station.

Senator NELSON. Not just the transportation cost, but the \$1.2 billion per year that Mr. Martin indicated just to keep the Station alive. So commercial companies would have to pick that up. You're talking about commercial companies suddenly taking such a large bite of the financial pie. It's possible they might choke on it, isn't it?

Mr. GERSTENMAIER. Again, I think we have to be careful as we think about the next platform in low Earth orbit. The Space Station, as you described in your opening remarks, is amazing in terms of size and complexity. These commercial stations could be dramatically simpler and dramatically smaller, and, potentially, the operating costs for those and some of the transportation costs can be reduced some amount by having a smaller capability.

We've seen some things now where the cargo providers are doing an after-mission activity with their cargo vehicles. They actually fly an extended mission after they're done delivering cargo to Station. That could serve a function of a space station to be crew tended, in a sense, not even in orbit for a permanent amount of time and return.

So I think we have to open up our thinking about what that new commercial station is and recognize that having a commercial entity take on the full cost of ISS doesn't make sense, but is there another model that still can give us the capability we need for reduced costs in maybe a different manner and innovative way of achieving it, and that's what we want to start exploring with companies in the near term, because at some point, Station will wear out. Station will no longer be supportable. We're going to have to deorbit Station. We want to make sure that event doesn't occur without us being prepared to look at a transition to another activity in low Earth orbit that can keep this continuous presence moving forward.

Senator NELSON. Well, I would suggest, Mr. Gerstenmaier, that I can speak on behalf of Senator Cruz and myself and say that as you do all of this planning, you also ought to plan for the alternative that the Station is going to stay alive until 2028 and even beyond. And as you look at your different scenarios, I would recommend that you do that because this Committee is going to require that.

Mr. Martin, does the ISS Transition Report adequately consider the risk of ending the ISS program in 2025?

Mr. MARTIN. We don't believe, based on our work, that it does, Senator.

Senator NELSON. What are your impressions of the Transition Report and the manner in which it was influenced by the Administration?

Mr. MARTIN. Senator, I can't speak to the latter part of your question because we have no knowledge of the input that OMB had or didn't have on the language. But looking at the report—and, again, based on the OIG's work—the report is—apart from describing a high-level framework and using words—dropping words like “robust economy in low Earth orbit”—we think that a lot of the conclusions or observations are overly optimistic in nature, particularly with the ability over the next 6 years to generate a sufficient

economy in low Earth orbit to pull off this plan. So we have serious reservations about it, sir.

Senator NELSON. Of the \$3.5 billion that NASA spends on ISS operations, transportation, and research each year, roughly \$1 billion goes, as you have already indicated—\$1.2 billion—to operating and maintaining the Station itself. The ISS Transition Report makes it clear that NASA will continue to need access to low Earth orbit, even as we move to exploring Mars.

The report says NASA is going to keep paying for research and for transportation to low Earth orbit, yet it doesn't say how transitioning to a privately-run Space Station or platform will actually save money. If a commercial space station exists by 2025, it won't be free.

How, Mr. Gerstenmaier, will using commercial platforms in low Earth orbit save NASA money?

Mr. GERSTENMAIER. Again, it has to come from the things we described. There needs to be some ability for the commercial sector to generate revenue in low Earth orbit on their own so they have a revenue stream separate from the government, or other government agencies contribute to the funding. That lowers some of the cost, or the cost is shared now across a community rather than just NASA paying for that cost. The other way would be if we back off on some of the capability and we have less functionality in low Earth orbit such that it costs less to maintain that functionality in low Earth orbit.

Those would be two examples that we need to investigate and see which ones of those have the potential of yielding the benefit that we describe or we would like to try to get by making this transition.

Senator NELSON. So, Mr. Martin, I ask you, based on the work of the Office of Inspector General, is the commercial industry ready to assume the cost of operating and maintaining the ISS?

Mr. MARTIN. We don't believe so, and we think the—we had some specific concerns with the Transition Report. If you look on page 27, it talks about an STPI study that assesses the economic viability of a commercial low Earth platform. Some of the assumptions that this study uses are belied by the chart that the Chairman just put up. The operating assumption in that study was the cost of an astronaut transportation to low Earth orbit was \$20 million. Last time I looked, it was closer to \$84 million per seat.

In addition, on page 29 of the Transition Report was an interesting comment about venture capitalists that were contacted by the study writers to assess the economic viability. No venture capitalists that they spoke with for this report would invest in a commercial platform in low Earth orbit until there was much more clarity on revenue and costs.

Senator NELSON. On the basis of what you just said, if I were trying a jury trial, I would say, "Your Honor, the plaintiff or the defense rests."

Are there areas in which NASA could save cost under the current ISS program?

Mr. MARTIN. Myself or Mr. Gerstenmaier?

Senator NELSON. You, Mr. Martin.

Mr. MARTIN. I'm sure there are, and they have—they've consolidated contracts, they've moved from—to fixed price contracts with its main contractor, Boeing. There are lots that they've done over the past five, 10 years, and our hats are off to the managers at NASA for that, and I'm sure that there are additional efficiencies that they could identify in the coming years.

Senator NELSON. And then there's the question of demand. NASA's goal is to be one of many users of commercial space stations. But right now, I don't see who those non-government users are.

Mr. Gerstenmaier, do you expect—who would be the one that would join NASA for LEO services on a commercial space station?

Mr. GERSTENMAIER. Again, I think if we look at what's going on on the Station today, we don't see a single user that's going to come in and take a majority stake in the operations on the Station or have a majority activity. But what we're starting to see for the first time is we're starting to see a variety of companies find benefits that they can gain by doing research onboard the Station.

So the pharmaceutical companies, of which you're well aware, have been doing research into various drugs on Station. They've been using animal models and plant models to go look at various drug efficiencies, and some of those are having very interesting and positive benefits. The fact that the human genome changes slightly in space is also very intriguing to drug companies and other folks. There's some very novel new treatments that may come out for disease that we face that are coming that companies could gain revenue from.

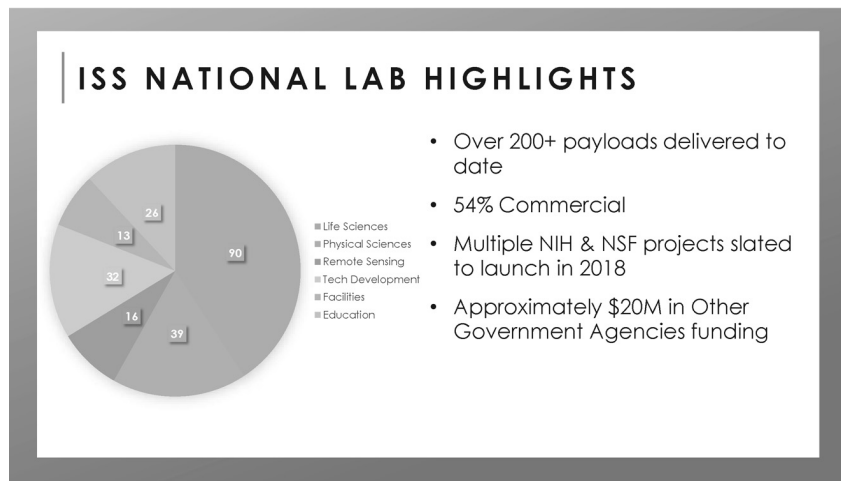
We're also beginning to start to see some manufacturing companies actually fabricate some material in space. There's some fiber optic material that's being manufactured today that, again, has the potential of being a better fiber conductor of optical transmissions on the Earth.

So, again, I would say it's too early to say that there's any one company, any one discipline, but there are a variety of areas and disciplines that show promise. Our job, along with Commerce and others, is to figure out ways that we can enable that industry to continue to investigate and see through their entrepreneurial and their innovative understanding that they can generate a case to generate revenue, and then at that point, they can start picking up some of the burden that we carry in space. But, again, I think it's a slow step-wise process.

Senator NELSON. Thank you for that comprehensive answer, and, if you would, since you have just made the case for extending the ISS, would you provide to the Committee examples of all those things that are going on that you just referenced for the Committee's perusal and probably the Committee's wanting to talk about it? Because the general public doesn't really understand some of the research that is quite dramatic, as you said, on pharmaceuticals that is going on.

[The information referred to follows:]

Please see the attached slides for examples of entities involved in the ISS National Laboratory and their research areas.



EXAMPLE EXISTING CUSTOMERS

LIFE SCIENCES	PHYSICAL SCIENCES	TECHNOLOGY DEVELOPMENT	REMOTE SENSING
Novartis	Procter & Gamble	Hewlett Packard	BioOptoSense
Merck	Nemak	AIRBUS DS Space Systems	HySpeed Computing
Houston Methodist	Milliken	Astrileux Corporation	Michigan Technological University
Nanobiosym	Target Corporation	Honeywell	Southwest Research Institute
iXpressGenes	GE	Business Integra	
The Scripps Research Institute	Delta	Made In Space	
Oncolinx Pharmaceuticals	Ras Labs	Cornell University	
Stanford University	Georgia Institute of Technology	Novopyxis	

FY17: EXAMPLE NEW CUSTOMERS

- Michael J. Fox Foundation: Disease research
- Budweiser: Crop science
- Massachusetts Institute of Technology: Musculoskeletal disease
- Time, Inc.: Educational outreach
- Hewlett Packard Enterprise: Tech validation
- Sanofi Pasteur: Immune response and aging
- The Boeing MassChallenge Technology in Space awardees (start-up companies):
 - Angiex, Inc.: Cancer drug testing
 - Dover Lifesciences: Drug discovery
 - LambdaVision, Inc.: Retinal prosthetics

IMPLEMENTATION PARTNERS

- Over 30 implementation partners working with companies & researchers to fly projects to the ISS National Lab
- 12 commercial facilities currently on station

Photo: NanoRacks

CURRENT NATIONAL LAB VALUE AND IMPACT

~1.5 years
projected time-to-market acceleration
(for a subset of projects)

\$900M
projected incremental revenues

\$110B+
estimated addressable market

20+
new solution pathways
(a measure of innovation that can lead to a major advance in knowledge or new intellectual property)

Senator NELSON. Since we have a vote in progress, Mr. Chairman, I think I'll stop right there. I thank the witnesses, thank them for their expertise, and I think that the purpose of this hearing has been accomplished.

Senator CRUZ. Thank you, Senator Nelson.

We just heard the defense rest, and I will say my friend, Senator Matlock, would receive a directed verdict if this were, indeed, a courtroom.

Senator NELSON. If you were the judge, I'm sure.

[Laughter.]

Senator CRUZ. I'm going to ask just a couple of very brief questions, and we're going to wrap this hearing up.

Mr. Gerstenmaier, a minute ago, you were having a discussion with Senator Nelson about pharmaceutical research. If a billion

dollar drug is created due to the research on the ISS, what claim would NASA have to the intellectual property, and what share, if any, of the revenue would NASA receive?

Mr. GERSTENMAIER. Again, we can—that's a pretty detailed answer that comes from that, and we can go look at that. We've been trying to look at the advantages of providing—if a company operates with NASA, typically, we own the intellectual property rights if they participate and develop something in our facilities. But if they put in the majority of the work, all the innovation comes from their side, all the creativity comes from their side, then they should rightfully have ownership. So we've been trying to look at ways that we could amend or clarify what our ownership of intellectual property right is.

Typically, we have those rights. We typically don't ever grab those rights from someone that does research, but we own those rights. That's held some people back from doing research on Station, because there's a significant amount of work that these companies will have to invest to get that revenue. They're going to have to not only make the discovery on Station, but then they're going to have to take it through maybe 10 years of Federal drug agency trials to actually get a pharmaceutical that's on the market.

So they'll make a significant amount of investment in that that is probably not appropriate for us to go capture some revenue from that, because they've earned that through the money they've put in place. So we'll work with that, and we'll see how that looks. But I think, in general, we would like to have them—if they put the revenue in, put the time in, put the creativity in, that's their intellectual property that they should be able to use.

[The information referred to follows:]

Answer: There are no special or different intellectual property requirements specifically applicable to research on the ISS. Under the current statutory and regulatory regime, commercial entities retain all commercial rights in intellectual property created through use of the ISS.

NASA does not have authority to accept or retain royalties (or profit-share) for commercially-owned technologies even when those technologies are developed using government support or assets. Government agencies (including NASA) are only authorized to collect and retain royalties (as a share of sales or profits) from private entities only when the private entities are commercializing *Government-owned technologies* pursuant to a technology transfer license. (See 35 USC 209 and 15 USC 3710c). Similarly, NASA is not authorized to seek or retain a share of profits or revenue earned by a commercial entity through making a commercial product on the ISS.

Senator CRUZ. So does NASA have any agreements in place for sharing revenue that could be utilized to lower ISS costs?

Mr. GERSTENMAIER. Not in that direct revenue sharing sense, no.

Senator CRUZ. Well, I think that may be ripe for further discussion, and I look forward to working with you on that.

Let me just say, finally, I want to thank all of the good men and women that work at NASA, the incredible scientists, the incredible leaders, astronauts, brave men and women that are leading our country's space program. We are grateful for your service. As Chairman of this Committee, I view it as a responsibility that I take very seriously to stand up and fight for you. I know Senator Nelson views that responsibility with the same gravity. So I thank you both for your testimony.

The hearing record is going to remain open for two weeks. During this time, senators are asked to submit any questions for the record, and upon receipt, the witnesses are requested to submit their written answers to the Committee as soon as possible.

And with that, this hearing is adjourned.

[Whereupon, at 3:36 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO
WILLIAM H. GERSTENMAIER

Question 1. Please provide examples of the types of users on ISS today that could eventually be paying customers of a commercial space station? What types of activities are these users engaged in?

Answer. Please see the attached slides for examples of entities involved in the International Space Station (ISS) National Laboratory and their research areas.

Question 2. At the hearing you discussed the new Commercial LEO Development program that is supposed to help NASA achieve its goal of being one of many users of commercial space stations. The FY 2019 Budget provided very little information about this new program. Please provide a summary and a timeline of the activities the program will conduct.

Answer. The primary purpose of the Commercial low-Earth orbit (LEO) Development program is to spur a vibrant, sustained U.S.-led, commercial LEO human spaceflight marketplace where NASA is one of many customers. The vision includes one or more privately-owned/operated platforms—either human-tended or permanently-crewed—together with transportation capabilities for crew and cargo that enable a variety of activities in LEO, where those platforms and capabilities are sustained to a greater degree than today by commercial revenue. These future platforms may either leverage the ISS or be free-flying. NASA must also communicate its forecasted needs in LEO to allow the private sector to anticipate that demand in their business cases. With this vision, NASA is able to share the cost of a LEO platform with other commercial, Government, and international users. In the President's FY 2019 Budget Request, the runout is as below:

- FY 2019—\$150M
- FY 2020—\$150M
- FY 2021—\$175M
- FY 2022—\$200M
- FY 2023—\$225M

To achieve the Commercial LEO Development program's goals, a first activity will be to solicit inputs from industry on the development and operations of private on-orbit modules and/or platforms and other capabilities that NASA could eventually utilize to meet its long-term LEO needs as one of many customers. NASA is laying the groundwork for 2019 by working with industry in 2018 (including an industry day May 1, 2018) and releasing small study contracts focused on understanding how the commercial sector can be incentivized to support NASA's LEO needs. Based on these initial inputs, NASA expects to then conduct a full and open competition for public and privately funded module(s) and/or platform(s) attached to the ISS or free-flying in LEO, or other capabilities in FY 2019.

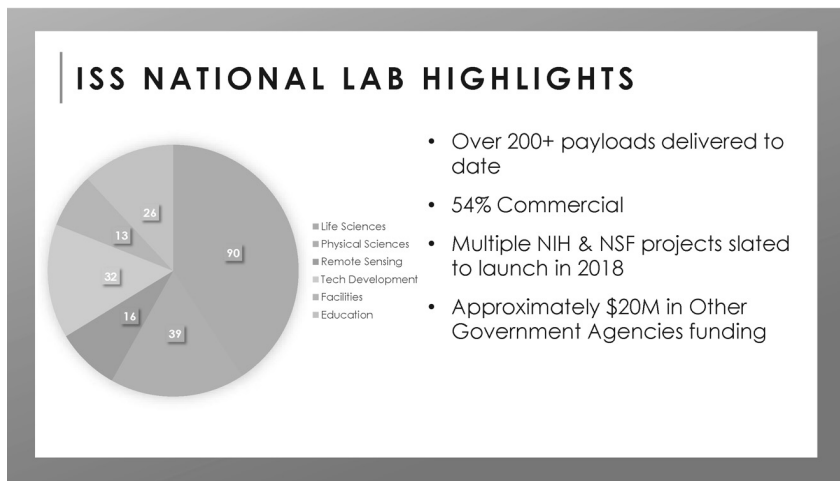
NASA also intends to use a portion of these funds to continue to stimulate non-NASA demand for LEO activities that will be needed to support private LEO platforms. For example, NASA has been investing—and will continue to invest—in commercial on-orbit facilities and integration costs for promising research leading to sustained non-NASA use of LEO, such as on-orbit manufacturing. NASA has been covering transportation costs, which allows a variety of companies to experiment with different revenue-generating activities or demand for space-based activities. In addition, industry studies funded by this program will allow interested parties to specify what support they desire from NASA, what commercial opportunities they are pursuing, and viability of private industries' business cases. This could potentially include options such as: (a) access to a port on ISS; (b) access to NASA's experience and capabilities through its unique workforce with expertise in the design, construction, launch, operations, and/or utilization of orbital platforms; and (c) financial support provided through the Commercial LEO Development program. As

a companion activity to this program, NASA will develop a policy that ensures that NASA or ISS National Laboratory activities do not compete with the capabilities provided by commercial LEO platforms. Ultimately, the commercial sector must develop the demand market. NASA and the Department of Commerce can create an environment that will allow commercial companies to develop demand. The Agency will leverage best practices from other commercial programs as applicable.

Question 3. The ISS Transition Report describes in qualitative terms some of NASA's ongoing requirements in Low Earth Orbit. Does NASA plan to quantify these requirements? How are they being communicated to industry?

Answer. NASA's broad long-term LEO requirements are laid out in Section 4.1 of the ISS Transition Report. NASA is currently working to develop a more detailed forecast (including quantifying where possible) of future LEO needs and will communicate this forecast to industry through public forums. An initial forecast later this summer will include specific types of facilities and capabilities that NASA will need, such as volume and interfaces for continued on-orbit testing of life support technologies, and research rack space. Further maturation of these forecasts will define estimates of crew time, upmass, and downmass. In order to ensure that private industry is prepared to provide the services and capabilities that support NASA's needs in LEO, NASA is proposing a step-wise transition of LEO human spaceflight operations from a Government-directed activity to a model where private industry is responsible for how to meet and execute NASA's requirements, as well as the needs of commercial operators. In order to effect a smooth transition, provide private industry with a vision of the future work, and allow NASA to plan and alter its activities, NASA is proposing that this transition of LEO human spaceflight responsibility to private industry will be essentially complete by 2025. This will give NASA time to engage with industry to begin transforming the many NASA-directed activities that are currently performed through several contracts into more of a public-private partnership and/or services contract(s) model where NASA's current responsibilities are executed and managed by private industry. This time period will also provide the opportunity for NASA and private industry to engage with stakeholders and to only proceed when industry has matured and is capable of executing NASA's requirements.

On May 17, 2018, NASA released a research announcement requesting proposals to study the future of human spaceflight commercialization in LEO. The research announcement solicits industry concepts detailing business plans and viability for habitable platforms, whether using the ISS or a separate free-flying structure, that would enable a space economy in LEO in which NASA is one of many customers. NASA will continue to have a need in LEO for regular crewed operations, long-term technology development and demonstrations, space and life sciences research, and opportunities for astrophysics, space, and Earth Science research. Access to an orbital platform on which to conduct these activities will be key as NASA and its commercial and international partners prepare for crewed missions to the Moon and beyond. NASA anticipates awarding multiple four-month, fixed priced contracts, not to exceed \$1M per award. Selection is expected to take place in July with the final reports delivered to NASA in the December timeframe. Through these studies, NASA is looking forward to learning how industry plans to meet NASA's ongoing needs in LEO as well as develop non-NASA demand.



EXAMPLE EXISTING CUSTOMERS

LIFE SCIENCES	PHYSICAL SCIENCES	TECHNOLOGY DEVELOPMENT	REMOTE SENSING
Novartis	Procter & Gamble	Hewlett Packard	BioOptoSense
Merck	Nemak	AIRBUS DS Space Systems	HySpeed Computing
Houston Methodist	Milliken	Astrileux Corporation	Michigan Technological University
Nanobiosym	Target Corporation	Honeywell	Southwest Research Institute
iXpressGenes	GE	Business Integra	
The Scripps Research Institute	Delta	Made In Space	
Oncolinx Pharmaceuticals	Ras Labs	Cornell University	
Stanford University	Georgia Institute of Technology	Novopyxis	

FY17: EXAMPLE NEW CUSTOMERS

- Michael J. Fox Foundation: Disease research
- Budweiser: Crop science
- Massachusetts Institute of Technology: Musculoskeletal disease
- Time, Inc.: Educational outreach
- Hewlett Packard Enterprise: Tech validation
- Sanofi Pasteur: Immune response and aging
- The Boeing MassChallenge Technology in Space awardees (start-up companies):
 - Angiex, Inc.: Cancer drug testing
 - Dover Lifesciences: Drug discovery
 - LambdaVision, Inc.: Retinal prosthetics

IMPLEMENTATION PARTNERS

- Over 30 implementation partners working with companies & researchers to fly projects to the ISS National Lab
- 12 commercial facilities currently on station

CURRENT NATIONAL LAB VALUE AND IMPACT

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. EDWARD MARKEY TO
WILLIAM H. GERSTENMAIER

Research Conducted on the ISS. Since 2005, the International Space Station has been a platform on which our astronauts carry out groundbreaking scientific research in low-Earth orbit. The ISS is the only microgravity research platform of its kind. This research on engineering, physical sciences, and biology, is absolutely necessary as we look to exploring our Moon, Mars, and beyond. NASA has always held that QUOTE, “Failure is not an option.” However, the Administration’s proposal to decommission the ISS in just seven years puts this pivotal research in jeopardy and without it, failure is inevitable.

Question 1. Mr. Gerstenmaier, it was mentioned that six out of 20 human health risk assessments will *not* be completed by the Administration’s proposed decommission date of ISS in 2025. How can you guarantee that these critical assessments and other scientific research will continue uninterrupted in low-Earth orbit?

Answer. The Administration is not proposing to decommission the ISS in seven years. The Administration is proposing to end direct Federal funding of the ISS by

2025. Research that has not been completed by the end of 2024 will be conducted on whatever platforms—whether they be new commercial platforms or commercially-operated ISS elements—are available in 2025. NASA wants to ensure there is no gap between ISS in its present operating model and what follows it.

Question 2. Do you believe the private market and NASA will be able to support this research, including a reliable platform, by the mid-2020s?

Answer. Yes. NASA has been able to support this research already even in the absence of a robust commercial market. NASA's Commercial low-Earth orbit (LEO) Development effort will explore options for conducting human LEO operations and research beyond 2025, and encourage the development of viable commercial platforms and operations. In support of this, on May 17, 2018, NASA released a research announcement requesting proposals to study the future of human spaceflight commercialization in LEO. The research announcement solicits industry concepts detailing business plans and viability for habitable platforms, whether using the ISS or a separate free-flying structure, that would enable a space economy in LEO in which NASA is one of many customers. NASA will continue to have a need in LEO for regular crewed operations, long-term technology development and demonstrations, space and life sciences research, and opportunities for astrophysics, space, and Earth Science research. Access to an orbital platform on which to conduct these activities will be key as NASA and its commercial and international partners prepare for crewed missions to the Moon and beyond.

Commercial Partnerships. Several of my Subcommittee colleagues and I are working on bipartisan commercial space legislation and one of my top priorities in this bill is to make it easier for smaller businesses to partner with NASA for use of assets and facilities in order to build up the commercial market. Mr. Gerstenmaier, in your testimony you state that "NASA's vision for low-Earth orbit is a sustained U.S. commercial human spaceflight marketplace where NASA is one of many customers."

Question 3. What do you think are the biggest challenges and impediments facing small businesses in building working partnerships with NASA?

Answer. Through Requests for Information (RFIs) and other interactions since 2014, including workshops with external stakeholders (most recently in August 2017), industry has identified the following challenges and barriers to achieving the vision of a self-sustaining marketplace in LEO:

- Uncertainty Concerning Future Availability and Uses of ISS/LEO Platforms;
- Cost of Transportation/Access;
- Government Acceptance of the Premise that Commerce has Value;
- Ability of Government Astronauts to Participate in Commercial Activities;
- Lack of Current Commercial Pricing Structure;
- Flexibility in Contracting and Public/Private Partnership Agreement Mechanisms; and
- Recognition of Intellectual Property (IP) Rights;
- Lack of a clear demand signal from Government; and
- Threat of competition by the Government that would undercut private investment.
- Foreign competition.

Question 4. Do you think these challenges will be overcome in time for the proposed decommissioning of ISS in the mid-2020s?

Answer. In order to achieve the vision of a self-sustaining marketplace in LEO, NASA will work together with industry to overcome these challenges. Some can be addressed through the development of an ISS commercial use policy and pricing structure for ISS services. Cost of transportation/access is expected to continue to be a significant barrier, particularly for small businesses. By setting 2025 for the end of direct Federal funding for ISS and releasing the RFP noted above, the Agency has spurred the discussion with its about how best to realize a commercial LEO environment and provided a time-frame for the resolution of the challenges.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
WILLIAM H. GERSTENMAIER

ISS Funding Deadlines. I am concerned that setting an arbitrary deadline for ending direct funding to ISS increases the risk that NASA will lose access to low Earth orbit for a period of time. I propose that it would be better to make a decision

to end funding based on the ability for commercial providers to meet NASA's needs in low Earth orbit.

Question 1. What sort of capabilities will commercial providers need to demonstrate in the near term to give us confidence that we are on track toward healthy public-private partnerships in low Earth orbit?

Answer. On May 17, 2018, NASA released a research announcement requesting proposals to study the future of human spaceflight commercialization in low-Earth orbit (LEO). This commercial LEO NASA Research Announcement is the next step in enabling a LEO space marketplace. The announcement solicits industry concepts detailing business plans and viability for habitable platforms, whether using the International Space Station (ISS) or a separate free-flying structure that would enable a space economy in LEO in which NASA is one of many customers. Via this announcement, industry is tasked to identify ways to stimulate demand for commercial LEO services with a goal to sustain the space marketplace. Additionally, the announcement seeks industry input about the role of Government and evolution of the ISS in the process of transitioning U.S. human spaceflight activities to a non-Governmental commercial human spaceflight enterprise in LEO.

NASA will continue to have a need in LEO for regular crewed operations, long-term technology development and demonstrations, and Earth, space and life sciences research. Access to an orbital platform on which to conduct these activities will be key as NASA and its commercial and international partners prepare for crewed missions to the Moon and beyond.

Question 2. If we start planning to end funding by 2025, but it becomes apparent before that deadline (for example in 2022) that this will result in an interruption in access to low Earth orbit, would costs of changing plans to ensure continued access to low Earth orbit exceed currently planned costs in those years leading up to 2025?

Answer. The proposal to discontinue direct Federal funding to ISS by 2025 represents a balance among the need to continue to conduct exploration-related research in LEO to prepare for deep-space missions, the recognition that the commercial sector is rapidly developing space capabilities that can support the requirements of both Governmental and non-Governmental customers, and the need for NASA to utilize the Moon as a stepping-stone to eventual human missions to Mars. NASA is laying the groundwork (e.g., the issuance of the RFP noted above) to ensure that the Agency will be able to meet its LEO requirements after the end of direct Federal funding to the ISS. The current budget leading up to 2025 does not preclude continued access to LEO beyond 2025 should no alternate platforms become viable.

Commercializing Low Earth Orbit. The ISS Transition report includes forecasts from STPI saying a commercial operator will lose a significant amount of money under all but the rosier of scenarios.

Question 3. What specific evidence can you cite that points toward a robust market for low Earth orbit and likely commercial success?

Answer. While the commercial LEO market is still developing the ISS National Lab, managed by the Center for the Advancement of Science In Space (CASIS), has been a key enabler of the expanded commercial use of LEO. Since 2011, more than 200 ISS National Laboratory research projects have been flown to the ISS—ranging from developing new drug therapies, to monitoring tropical cyclones, to improving equipment for first-responders on the ground, to producing unique fiber-optics materials. In the last several years, at least 50 percent of the ISS National Lab projects were new-to-space customers, and more than 50 percent involve commercial users (i.e., for-profit companies). CASIS has estimated a projected incremental revenue of more than \$900 million directly tied to National Laboratory projects to date.

The ISS National Lab is currently opening up the possibilities of the Station research environment to a diverse range of researchers, entrepreneurs, and innovators that could create entirely new markets in space. These areas include, but are not limited to the following: drug delivery systems; crop science; regenerative medicine; reaction chemistry; materials science; fluid dynamics and transport phenomena; on-orbit production and microgravity-enabled materials; protein crystal growth (also known as macromolecular crystal growth); and, Earth observation and remote sensing. These activities are part of a young portfolio of non-NASA projects that are beginning to benefit from increased access to the ISS as well as shorter timeframes from project concept to implementation on the ISS. The ISS National Lab portfolio's current positioning forecasts growth in the next ten years in areas such as cell and gene therapy, 3D bio-printing scaffolds, and aerospace projects using the LEO platform to raise technological readiness levels of next-generation LEO and beyond infrastructure systems. Additionally as discussed in question 1 above, the commercial

LEO NASA Research Announcement is the next step in enabling a LEO space marketplace.

As one example of a commercial use of ISS, NanoRacks' CubeSat Deployer is a stackable, modular, ground loaded launch case which is designed to meet the growing demand to deploy CubeSat format satellites from ISS for a variety of customers. As of June 2018, over 600 payloads have been launched to ISS via NanoRacks services for the U.S. Government (including NASA), commercial entities, and a variety of international space agencies and other organizations.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GARY PETERS TO
HON. PAUL K. MARTIN

ISS Funding Deadlines. I am concerned that setting an arbitrary deadline for ending direct funding to ISS increases the risk that NASA will lose access to low Earth orbit for a period of time. I propose that it would be better to make a decision to end funding based on the ability for commercial providers to meet NASA's needs in low Earth orbit.

Question 1. What indicators in the low Earth orbit market might demonstrate that we are headed toward a robust commercial environment?

Answer. The most significant indicator that a robust commercial environment exists in low Earth orbit is for commercial entities such as Goodyear, Merck or Proctor and Gamble to make significant monetary investments in low Earth orbit research and activity. Such an environment would require expansion beyond the more traditional investments in microgravity research and applications into broader commercial activities such as space tourism, satellite servicing, manufacturing of goods, and corporate research and development, all of which have yet to materialize.

Question 2. If we start planning to end funding by 2025, but it becomes apparent before that deadline (for example in 2022) that this will result in an interruption in access to low Earth orbit, would costs of changing plans to ensure continued access to low Earth orbit exceed currently planned costs in those years leading up to 2025?

Answer. If NASA, for example, decides in 2022 to retain and extend ISS operations beyond 2025, much of the added operations and maintenance costs will be determined by the level of investment needed to address aging systems and infrastructure issues as well as crew and cargo transportation payments to supporting companies such as Boeing, SpaceX and Sierra Nevada. Operations and maintenance costs are currently scheduled to decrease to about \$1.4 billion in the three years prior to 2025 because NASA would not be making advance payments for future repair parts or cargo and crew flights. Such payments to contractors typically begin up to 36 months before a flight occurs. If additional flights are scheduled, planned annual costs in the years leading up to 2025 would increase to \$3 to \$4 billion or about half of NASA's annual human space flight budget.

INTERNATIONAL SPACE STATION TRANSITION REPORT

PURSUANT TO

SECTION 303(C)(2) OF THE NASA TRANSITION AUTHORIZATION ACT OF 2017
(P.L. 115-10)

MARCH 30, 2018

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1.0: INTRODUCTION

This report responds to direction in the National Aeronautics and Space Administration Transition Authorization Act of 2017 (P.L. 115–10, hereafter “the Act”), Section 303(c)(1), to submit to Congress a report evaluating the International Space Station (ISS) as a platform for research, deep space exploration, and low-Earth orbit (LEO) spaceflight in partnership with its four foreign space agency partners, and the commercial space sector (see Appendix for text of the reporting requirement, excerpted from the Act).

The ISS represents an unparalleled capability in human spaceflight that is increasing knowledge of engineering and physical sciences, biology, the Earth, and the universe. This knowledge is benefiting life here on Earth and enhancing the competitiveness of U.S. private industry. The research and technology demonstrations onboard the ISS are not only providing the basis for extending human presence beyond the bounds of LEO and taking America’s next steps into the proving ground of cislunar space, but also advancing the competitiveness of U.S. private industry. Building on the partnership of five space agencies representing the 15 ISS Intergovernmental Agreement signatory nations, over 101 countries and areas have utilized, or are currently utilizing, the ISS. Astronauts have continuously lived aboard the ISS for over 17 years. Approximately one-quarter of the U.S. population today only knows a time when Americans have lived in space.

This report lays out NASA’s activities and future plans for operations, research, and development in LEO. “Transition,” (Section 3), as that term is used in Section 303 of the NASA Transition Authorization Act of 2017, discusses the LEO capabilities that the ISS currently provides the Nation, which include a sustained American presence in LEO, sustained American global space leadership, the continued development of a commercial space industry and a commercial space marketplace, the continued development of deep space exploration capabilities, and the continued return of research and development benefits to humans on Earth. “Transition” also discusses what NASA envisions the LEO landscape to look like in 2024 and beyond, as well as the key issues that need to be considered when contemplating ISS end-of-life and transition to other platforms. “Major Elements of Transition” (Section 4) goes into detail on the LEO commercial marketplace, the ISS’s role in the expansion of humanity into deep space, the benefits currently being returned to Earth from research on ISS, and an evaluation of the technical and cost implications of continuing to operate ISS through and beyond 2024. Section 5 provides a Summary.

2.0: EXECUTIVE SUMMARY

The NASA Transition Authorization Act of 2017 (P.L. 115–10) provided for an ISS Transition Report under section 303:

The Administrator, in coordination with the ISS management entity (as defined in section 2 of the National Aeronautics and Space Administration Transition Authorization Act of 2017), ISS partners, the scientific user community, and the commercial space sector, shall develop a plan to transition in a step-wise approach from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a low-Earth orbit non-governmental human space flight enterprise.

Uses of Low-Earth Orbit (LEO) Platforms

Preparing for Human Deep Space Missions

In order to prepare for human expeditions into deep space, the Agency must first conduct breakthrough research and test the advanced technology necessary to keep crews safe and productive on long-duration space exploration missions. An on-orbit platform like the ISS is necessary to mitigate 22 of the 33 human health risks in the portfolio identified by NASA’s Human Research Program in support of current and future deep space missions. NASA is also using the ISS as a testbed to fill crit-

ical gaps in technologies that will be needed for long-duration deep space missions. For example, elements of the ISS life support and other habitation systems will be evolved into the systems that will be used for deep space exploration missions and undergo long-duration testing. It is NASA's plan to first develop and demonstrate many critical technology capabilities using the ISS (and potentially other future platforms) as a permanently-crewed testbed prior to deploying these capabilities beyond low-Earth orbit (LEO). This approach is much more cost-effective and faster than conducting this research in cislunar space because of the risks inherent in operating so far from the Earth.

Global Leadership in Human Spaceflight

Consistent with the President's space policy directive, "*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 strength of the international partnership created through the ISS Program is a testament to U.S. leadership in space and to the aerospace expertise of all the nations involved. It serves as an example of how many countries can work together to design, build, operate, and maintain large, complex human space assets. As we consider the future of ISS and potential successors and prepare for human missions of exploration into deep space, it is important to reflect on the critical value of the proven partnership that has made the ISS possible, and to consider how to build on these relationships as NASA proceeds into cislunar space. The ISS partner agencies are looking for leadership in human spaceflight and LEO from the U.S. Informally, all of the partner agencies have indicated that they expect to continue cooperative activities with NASA as long as NASA continues to maintain America's commitment to the partnership.

Enabling a LEO Commercial Market

NASA's vision for LEO is a sustained U.S. commercial LEO human space flight marketplace where NASA is one of many customers. The vision includes one or more privately-owned/operated platforms—either human-tended or permanently-crewed—and transportation capabilities for crew and cargo, that enable a variety of activities in LEO, where those platforms and capabilities are sustained primarily by commercial revenue rather than relying on NASA and the U.S. Government as their main source of revenue as is the case today with the ISS. NASA must also communicate its forecasted needs in LEO to allow the private sector to anticipate that demand in their business cases. With this vision, NASA is able to share the cost of a LEO platform with other commercial, Government, and international users. This allows NASA to maximize its resources toward missions beyond LEO, while still having the ability to utilize LEO for its ongoing needs as described in Section 4.1.

In order to enable this vision, NASA is executing several public-private partnerships centered around the ISS to foster the development of customers for LEO capabilities, but also is maturing the supply industry to be able to meet future demands. NASA is also initiating the Commercial LEO Development program to further the development of private on-orbit capabilities beyond what is available today through the ISS.

The Commercial Resupply Services (CRS), the Commercial Crew Program, and the ISS National Lab are key complementary enabling activities to enable this vision. Under the CRS contracts, NASA's two commercial cargo partners, Space Exploration Technologies (SpaceX) and Orbital ATK, have demonstrated not only the ability to provide cargo deliveries to ISS, but also the flexibility to recover effectively from mishaps. The addition of the Sierra Nevada Corporation as a third commercial service provider will add significant on-orbit and return capability. Both Orbital ATK and Sierra Nevada Corporation have begun to investigate options to perform significant on-orbit operations after their primary cargo mission is completed. These two providers are able to provide an on-orbit research capability independent of ISS. NASA's commercial crew partners, SpaceX and the Boeing Company, are developing the Crew Dragon and CST-100 Starliner spacecraft, respectively. These companies have made significant progress toward returning crew launches to the U.S., and NASA anticipates having these capabilities in place by 2019 to regularly fly astronauts safely to and from ISS. The crew and cargo vehicles, as well as the launch vehicles developed by these providers, have the potential to support future commercial enterprises as well as ISS.

The Center for the Advancement of Science In Space (CASIS) manages the activities of the ISS National Laboratory to increase the utilization of the ISS by other Federal entities and the private sector. CASIS works to ensure that the Station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological, and industrial communities. The ISS National Laboratory is

helping to establish and demonstrate the market for research, technology demonstration, and other activities in LEO beyond the requirements of NASA. Commercial implementation partners are now bringing their own customers to the ISS through the National Lab as well.

Benefitting Humanity

Across a range of disciplines and applications, research on a crewed space platform ultimately benefits people on Earth. In the physical and biological sciences arena, a LEO space platform can allow researchers to use microgravity conditions to understand the effect of the microgravity environment on microbial systems, fluid physics, combustion science, and materials processing, as well as environmental control and fire safety technologies. Technologies developed for use in space, such as water purification technologies, can have applications on Earth. Crewed platforms can also be the site of sensors that provide data used to support activities such as disaster relief.

ISS Transition

ISS Transition Principles

There are several key principles to any strategy or decision to be made regarding the ISS and the future of LEO and NASA's role as one of many customers of services or capabilities that are provided by private industry as part of a broader commercial market. The following principles will ensure uninterrupted access to LEO capabilities to enable NASA and the Nation's long-term interest in LEO and human spaceflight exploration including supporting National security objectives, such as a competitive industrial base and U.S. leadership:

- Continuity among NASA's LEO, deep space exploration, and development and research activities and missions toward expanding human presence into the solar system;
- Expanding U.S. human spaceflight leadership in LEO and deep space exploration, including continuity of the relationship with our current ISS international partners;
- Increase platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs;
- Spur vibrant commercial activity in LEO;
- Maintaining critical human spaceflight knowledge and expertise within the Government in areas such as astronaut health and performance, life support, safety, and critical operational ground and crew experience;
- Continuing to return benefits to humanity through Government-sponsored basic and applied on-orbit research;
- Continuing Government-sponsored access to LEO research facilities that enable other Government agencies, academia, and private industry to increase U.S. industrial competitiveness and provide goods and services to U.S. citizens; and
- Continuing to reduce the Government's long-term costs through private industry partnerships and competitive acquisition strategies.

ISS Transition Strategy

As part of a cohesive exploration strategy, NASA intends to begin shifting responsibility for meeting its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness that would offer the prospect of lower cost to the Government to enable NASA to apply more personnel and budget resources on expanding human spaceflight beyond LEO and enhancing U.S. leadership in human spaceflight around the world. Among the benefits beyond the prospect of lower operational costs for a LEO platform, shifting focus to industry can additionally reduce the infrastructure burden on NASA has already been demonstrated at NASA facilities at Kennedy Space Center, Johnson Space Center, Stennis Space Center, and the Michoud Assembly Facility.

In order to ensure that private industry is prepared to provide the services and capabilities that support NASA's needs in LEO, as outlined in the key principles above, and to enable private industry to develop markets and customers beyond the Government, NASA is proposing the following approach:

1. Begin a step-wise transition of LEO human space flight operations from a Government-directed activity to a model where private industry is responsible for how to meet and execute NASA's requirements. Consistent with the *ISS Transition Principles*, this does not mean NASA is "commercializing the ISS." In-

stead, NASA maintains leadership and governing responsibilities as outlined in the Partnership agreements, and continues to maintain the essential elements of human spaceflight such as astronaut safety and the high-risk exploration systems.

In order to effect a smooth transition, provide private industry with a vision of the future work, and allow NASA to plan and alter its activities, NASA is proposing that this transition LEO human space flight responsibility to private industry be essentially complete by 2025. This will give NASA time to engage with industry to begin transforming the many NASA-directed activities that are currently performed through several contracts into more of a public-private partnership and/or services contract(s) model where NASA's current responsibilities are executed and managed by private industry. This time period will also provide the opportunity for NASA and private industry to engage with stakeholders and to only proceed when industry has matured and is capable of executing NASA's requirements. The transition of ISS will ensure that there are private companies with the experience and expertise to operate various types of platforms in LEO by the mid-2020s. This transition to private industry must be done in a cost-effective manner and not exceed current operational costs.

Consistent with the *ISS Transition Principles*, NASA will continue discussions with the ISS International Partners to help shape the long-term future of LEO.

2. Solicit information from industry on the development and operations of private on-orbit modules and/or platforms and other capabilities that NASA could utilize to meet its long-term LEO requirements that are consistent with the *ISS Transition Principles*. The scope of the solicitation may include risk reduction development activities, or modules or elements that could either be attached to the ISS or be free-flying. The solicitation may also include private industry conducted studies on the future of the ISS platform that may be combined with private industry objectives in LEO.

NASA will begin with a solicitation in FY 2018 to gather broad industry input on interest in meeting NASA's long-term needs and objectives that should lead to multiple awards in FY 2019 funded out of the Commercial LEO Development program.

Throughout this approach, NASA will also be requesting market analysis and business plans from private industry in order to gauge the depth of possible commercial markets as they apply to industry's ability to meet NASA's needs and requirements with a base where NASA is only one of many customers. This approach is also dependent on NASA identifying our long-term requirements for LEO, which are highlighted in Section 4.1.

ISS Considerations and the Eventual Future of the ISS Platform

From a structural integrity analysis standpoint, the ISS platform is expected to have significant structural life well beyond 2028 (based on the current assessment period). Many of the ISS modules, particularly the modules launched in the later years of ISS assembly, are likely to have structural life well into the 2030s (see section 4.4). Although it is thus likely technically feasible to continue to operate the ISS well beyond 2028, it is also necessary to consider the costs of operating this complex facility as we have been doing (approximately \$1.1 billion per year for O&M in the outyears) as we consider the future of the ISS platform.

NASA's international partners are likely to have different levels of interest in continuing the ISS and in moving to new LEO programs. There are common themes across the partnership, however, in considering the future of ISS and exploration, such as:

- Reducing operational costs;
- Offering frequent visible national astronaut opportunities;
- Continuation and continuity of research and technology development activities;
- Balancing LEO and exploration;
- Maturation of commercial opportunities.

The eventual future of the ISS, whether it is transitioning the operations of the ISS platform to private industry through the use of public-private partnerships, augmenting it with privately developed modules, combining portions of the ISS with a new private platform, or beginning anew with a free-flying platform and de-orbiting the ISS, will be evaluated using the *ISS Transition Principles*.

Fast Forwarding to the mid-2020s

Continuing with current policies, including the Commercial LEO Development program, NASA can project what the LEO landscape may look like in the mid-2020s. In predicting the LEO landscape, areas that have a high degree of certainty include maintaining our strong global leadership position with the continuation of the ISS through 2024, validating commercial cargo and crew transportation costs, and completing the majority of NASA exploration-related human and systems research and demonstration. Other nations will have deployed their own space station(s). Examples of areas that will have a lower degree of certainty include whether or not private industry capabilities have matured enough to satisfy NASA's needs and requirements, and whether or not a viable commercial market has matured in LEO that is not dependent on Government support. The Commercial LEO Development program, along with expanded ISS public-private partnerships, is targeted to address these uncertainties.

NASA's long-term LEO requirements

NASA and the U.S. have a long history of human spaceflight leadership and LEO research and technology development that go all the way back to the Mercury program through Gemini, Apollo, Skylab, the Space Shuttle, and the ISS.

Regardless of the eventual fate of the ISS platform itself, NASA is expecting to maintain U.S. leadership in LEO and human spaceflight through lunar exploration and eventually to Mars consistent with the *ISS Transition Principles*. Within that context, NASA is planning to continue with the following LEO needs and objectives beyond the life of ISS:

- Maintaining the Partnership with our current ISS international partners and possibly adding new international and domestic participants;
- Regular LEO crewed operations, including short and long durations:
 - Enables operational space proficiency;
 - Shift from human health and performance countermeasures development (the ISS portion of which is expected to be complete by 2024) to validations of integrated long-duration system, habitation, operations, and crew isolation;
- Long-term technology/systems development and demonstrations (*e.g.*, life support);
- Space life and physical sciences basic and applied research at current level and capabilities;
- National Laboratory-based research and technology development;
- Opportunities for astrophysics, space, and Earth Science research.

These long-term requirements, while similar to that of the current ISS Program, could be met with various types of modules or platforms that do not necessitate a vehicle (or vehicles) as complex as the ISS. Many of the research activities could be conducted on shorter-duration platforms, similar to the Shuttle, or even crewed extended platforms. These requirements are expanded upon in Section 4.1.

Conclusion

NASA believes that this is a well-balanced approach where the Agency's and other U.S. Government interests are protected and enhanced while offering the prospect of lower cost to the Government and opening new markets and new business models to the U.S. industrial base. This approach will also lay the foundation where NASA could be one of many customers in a LEO commercial marketplace and provides the basis for determining the long term future of the ISS Platform and LEO along with the ISS International Partners.

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.

3.0: TRANSITION

On November 2, 2017, NASA marked 17 years of continuous United States human presence in LEO onboard the ISS. The Station has enabled the U.S. to solidify its global space and innovation leadership across multiple capabilities and policy objectives. In determining where the U.S. wants to position itself in the mid-2020s, there are several key principles to any strategy or decision regarding the ISS and the future of LEO and NASA's role as one of many customers of services or capabili-

ties that are provided by private industry as part of a broader commercial market. Adhering to the following principles in considering ISS transition will ensure uninterrupted access to LEO capabilities for NASA and the Nation's long-term interests in LEO and human spaceflight exploration. National interests include supporting national security objectives of maintaining a competitive industrial base and U.S. leadership.

- Continuity between NASA's LEO, deep space exploration, and development and research activities and missions to expand human presence into the solar system;
Rationale: Continuity provides a key stabilizing factor in Government and industry due to the multi-decadal nature of spaceflight. Instability in policy and programmatic can result in misdirected efforts and funding and decreased capability and investment from Government, industry, and international partners.
- Expanding U.S. human spaceflight leadership in LEO and deep space exploration, including continuity of the relationship with our current ISS international partners;
Rationale: U.S. leadership in exploration and human spaceflight is based on the foundation of the ISS international partnership that has matured over 20 years. Expanding international partnerships will ensure that the U.S. continues its global leadership into the future.
- Increase platform options in LEO to enable more ISS transition pathways, security through redundant capabilities, and industrial capability that can support NASA's deep space exploration needs;
Rationale: Creating multiple dissimilar suppliers is a key element of fostering a commercial market and is also one of the key elements of securing the capabilities to needed to meet the long-term needs of NASA and the U.S. in LEO.
- Spur vibrant commercial activity in LEO;
Rationale: A vibrant commercial activity in LEO is essential to the goal of NASA becoming one of many customers in LEO. It is also key to lowering the cost of access to the Government and to other customers.
- Maintaining critical human spaceflight knowledge and expertise within the Government in areas such as astronaut health and performance, life support, safety, and critical operational ground and crew experience;
Rationale: The knowledge and expertise to expand human missions into deep space for long durations is required to be maintained over many years as well as many programs and missions that are inherently Government-led and -executed. This is due to the unique NASA mission of expanding human presence into the solar system.
- Continuing to return benefits to humanity through Government-sponsored basic and applied on-orbit research;
Rationale: Continuing NASA's portfolio in basic and applied research is a natural extension of the knowledge and expertise that the U.S. has developed in space over the past half century.
- Continuing Government-sponsored access to LEO research facilities that enable other Government agencies, academia, and private industry to increase U.S. industrial competitiveness and provide goods and services to U.S. citizens;
Rationale: With the creation of the ISS National Lab in 2010, the U.S. has taken the lead in enabling private industry and other Government agencies (such as NIH and NSF) to conduct research and technology development activities in LEO. These activities, though in its beginning stages, are producing results that could directly benefit the competitiveness of U.S. industry and quality of life for U.S. taxpayers. Continuing the National Lab and NASA's support will continue to be critical to the success of private industry and other Government agencies' research activities.
- Continuing to reduce the Government's long-term costs through private industry partnerships and competitive acquisition strategies.
Rationale: As industry becomes more capable in executing NASA's mission independently, NASA should leverage the competitiveness and efficiencies of private industry to realize cost reductions. Broad-based industry investments and capabilities also enhance the industrial capacity security of the U.S. to carry out not only NASA's missions but broader National goals.

Fast Forwarding to the mid-2020s

Continuing with current policies, NASA can project what the LEO landscape in the mid-2020s may look like. Some areas that can be projected with some confidence include:

- Americans have maintained a continuous presence on the ISS for over 24 years;
- NASA continues to lead a strong international ISS partnership;
- Commercial crew transportation to the ISS is operational, and has enabled the permanent addition of a 4th U.S. On-orbit Segment (USOS) crew member;
- Commercial cargo and crew transportation costs to ISS have been validated over several years;
- NASA is conducting human missions in cislunar space using a deep space capability such as the Lunar Orbital Platform-Gateway;
- NASA has completed the majority of exploration-related human research, life support, and other system demonstrations which are ready for incorporation into missions beyond cislunar space, including preparations for crewed orbital flights to Mars;
- Other nations are operating their own LEO space stations, possibly in partnership with other nations (including some of the ISS Partner nations), and potentially offering subsidized services.

Some areas that can be projected with less certainty include:

- How successful the Commercial LEO Development program has been in reducing the barriers to alternative approaches to support government and commercial LEO activities;
- Whether or not private industry users, have built self-sustaining business cases that include integration, transportation, and execution of their research or technology development for LEO capabilities;
- Whether or not other Government organizations, like the National Institutes of Health (NIH), have established long-term requirements for conducting research in LEO and have allocated funds to pay for overhead costs;
- Whether or not independent commercial market activities in LEO (*e.g.*, tourism, activities supporting the satellite sector, manufacturing products and services for use in space and on Earth, research and development, and media advertising and education) have been established;
- Whether or not ISS is a hub of the growing space economy, providing infrastructure services for a broad spectrum of Government, commercial, and academic users and serving as one of multiple consumers of LEO launch, on-orbit, and return services;
- Whether NASA has been able to reduce the cost of operating the ISS.

ISS Transition Strategy

Given the above *ISS Transition Principles* and the projected state of LEO in the mid-2020s, NASA intends to implement a transition strategy that builds upon the strengths of the projected U.S. position in LEO, and to mitigate the uncertainties. NASA intends to begin shifting responsibility for meeting its needs and requirements in LEO to the private sector by leveraging private industry capacity, innovation, and competitiveness. This will offer the prospect of lower cost to the Government to enable NASA to apply more personnel and budget resources on expanding human spaceflight beyond LEO and expanding U.S. leadership in human spaceflight around the world. Among the benefits beyond the prospect of lower operational costs for a LEO platform, shifting focus to industry can additionally reduce the infrastructure burden on NASA as already demonstrated at NASA facilities at KSC, JSC, Stennis, and MAF.

In order to ensure that private industry is prepared to provide the services and capabilities that support NASA's needs in LEO, as outlined in the key principles above, and to enable private industry to develop markets and customers beyond the Government, NASA is proposing the following approach:

1. Begin a step-wise transition of ISS operations from a Government-directed activity to a model where private industry is responsible for planning how to meet and execute NASA's requirements. Consistent with the *ISS Transition Principles*, this does not mean NASA is "commercializing the ISS." Instead, NASA maintains leadership and governing responsibilities as outlined in the Partnership agreements, and continues to maintain the essential elements of

human spaceflight such as astronaut safety and the high-risk exploration systems.

In order to incentivize private industry and to effect the transformation of NASA's responsibilities, NASA is proposing that this transition of ISS execution responsibility to private industry be essentially complete by 2025. This will give NASA time to engage with industry to begin transforming the many NASA-directed activities that are currently performed through several contracts into more of a public-private partnership model where NASA's current responsibilities are executed and managed by private industry. This time period will also provide ample opportunity for NASA and private industry to engage with stakeholders and to only proceed when industry has matured and is capable of the responsibility to execute NASA's requirements. The transition of ISS will ensure that there are private companies with the experience and expertise to operate platforms in LEO by the mid-2020s.

In FY 2018 NASA will begin to develop this strategy.

Also, in FY 2018 NASA intends to solicit inputs from private industry regarding interest in planning and executing the day-to-day ISS operations.

Consultations with the ISS partners and stakeholders are essential to developing an implementation strategy that could result in the day-to-day execution of the ISS being performed by private industry by 2025.

Additionally, in support of enabling further development of commercial market-driven activities onboard the ISS and its commercial cargo and crew systems, NASA is developing a commercial use policy for ISS resources including crew time, up-and down-mass, and crew rotation opportunities. This policy addresses private activities, such as tourism, private professional astronauts, marketing, and advertising that are outside the scope of the National Laboratory statutory activities such as education and research activities, and where there are legal, policy, regulatory or contractual gaps in NASA's ability to participate in such activities, even only as part of a transitional role to enable a LEO marketplace. A draft of this policy will be provided to our International Partners and also be made available for industry comment in FY 2018.

Consistent with the *ISS Transition Principles*, NASA will continue discussions with the ISS International Partners to help shape the future of the ISS platform and LEO after 2024.

2. Solicit information from industry on the development and operations of private on-orbit modules and/or platforms and other capabilities that NASA could utilize to meet its long-term LEO requirements that are consistent with the *ISS Transition Principles*. NASA will begin with a solicitation in FY 2018 to gather broad input on industry interest in meeting NASA's long-term needs and requirements that could lead to one or more awards in FY 2019 funded by the Commercial LEO Development program. The scope of the solicitation will include modules or elements that could either be attached to the ISS or be free-flying. The solicitation will offer funded and non-funded opportunities as well as asking what Government services or capabilities industry is interested in. The solicitation will also request inputs on the relative merits of Government-provided funds vs. no funding. The result of this solicitation could result in NASA purchasing services and/or capabilities in the mid-2020s.

Throughout this approach, NASA will also be requesting market analysis and business plans from private industry in order to gauge the depth of possible commercial markets as they apply to industry's ability to meet NASA's and other customers' needs and objectives with a base where NASA is only one of many customers. This approach is also dependent on NASA identifying our long-term requirements for LEO; which are highlighted in Section 4.1.

Additional Transition Activities

There are additional activities that NASA plans to execute in the near future that expand the enabling of a LEO commercial market, enable increased international cooperation beyond the current Partnership activities, help define a broader Government role in the development of a commercial market in LEO, and expand the role of other Government agencies in utilizing the ISS and other platforms in their research and development activities. Some of the activities include:

Enabling a LEO Commercial Market

Allowing private industry use of ISS resources and crew and cargo transportation for commercial for-profit activities – Offering on a competitive basis spare ISS resources, including crew time, commercial crew seats on NASA missions,

cargo transportation, and other resources for commercial for-profit activities. NASA is currently developing a commercial use policy for ISS resources including crew time, up-and down-mass, and crew rotation opportunities. This policy will address private activities that are outside the scope of the National Laboratory statutory activities such as educational and research activities. A draft of this policy will be provided for industry comment following consultation with intergovernmental stakeholders and ISS International Partners.

Global Leadership

- *Offering targeted crew opportunities to foreign nationals* – Based on broader national foreign policy objectives, invite targeted non-ISS Partner countries to join ISS missions in LEO on a one-time basis or long-term strategic basis. In accordance with the IGA and MOUs, NASA could offer existing seat opportunities aboard commercial crew transportation vehicles already on contract with NASA or expand the ISS crew for short durations. NASA would work to ensure that any such activities do not undercut any U.S. commercially-offered services.
- *Offering targeted research and utilization opportunities to foreign countries beyond the ISS Partners* – In accordance with the IGA and MOUs, NASA could offer additional opportunities to targeted non-ISS Partner countries that would benefit U.S. strategic scientific and technology leadership in many disciplines. These opportunities could be realized on the ISS or on new commercial platforms.
- *Building on the existing ISS partnership as a stepping stone to human space flight activities beyond LEO* – Under strong U.S. leadership, the resiliency of the international partnership, involving the harmonization and effective integration of over a dozen different political systems, budgetary mechanisms, and cultural, management, and industrial approaches, has laid the foundation for exploring beyond LEO. It demonstrates every day how numerous countries can work together to design, build, safely operate, and maintain large, complex space systems. As we consider the future of ISS and prepare for human missions of exploration into deep space, it is important to reflect on the critical value of the proven partnership that has made the ISS possible, and to consider how to build on these relationships. The ISS partner agencies depend on the U.S. to lead in human spaceflight, both in LEO and beyond.

Government Role in the Development of a LEO Commercial Market

With the objective of a sustained U.S. commercial LEO marketplace where NASA is one of many customers, NASA is executing a broad effort to address the policy and regulatory environment, development of capable private industry suppliers, and development of a demand for LEO services across broad areas of the economy. A main part of this effort will be successful execution of Commercial LEO Development program activities with private industry, which will focus on enabling, developing, and deploying commercial orbital platforms. This effort is expanded upon in Section 4.1. Working across Government agencies is among the efforts that NASA is pursuing.

- *Participate in a multi-agency working group among NASA, the Department of Transportation, and the Department of Commerce, and others to identify specific actions or legislation that would further the development of a commercial market in LEO* – The development of a commercial market has not been a traditional NASA policy objective. Though NASA for many years has supported the National aerospace industrial base, it is not well-equipped in the policy and regulatory fields that are the responsibility of other Government agencies. As the development of a commercial market in LEO is a long-term national goal, NASA recommends that a multi-agency working group be formed to address the policy, rules and regulations, and legislative actions that would be necessary to enable a market in LEO. Participation in such a multi-agency activity has also been endorsed by the National Space Council in March 2018:

At the request of the Vice President, the Acting Administrator of the National Aeronautics and Space Administration Robert Lightfoot agreed to work with the Secretaries of State, Commerce, and other interested members to develop a strategy for how we can further enable cooperation with our international and private industry partners to continue to develop the infrastructure and policies necessary to spur economic growth in space. This strategy will be reported out at the fall council meeting.

Expanding the Role of Government Agencies in LEO Research and Utilization

- *Initiate a government wide policy to access research needs for LEO platforms like the ISS across agencies such as NSF, NIH, NIST and others. The assessment could be conducted in cooperation with the National Academies as NASA currently does* – LEO platforms like ISS offer unique on-orbit science and technology development capabilities that can benefit Government-wide research beyond the NASA mission.

The National Lab, through CASIS, is working with other Government agencies to conduct research onboard the ISS that is based on limited objectives. Several of their experiments are already onboard the ISS, and more are planned. However, if the Nation is intent on funding the capability to perform research in LEO for many years to come, it would be prudent to initiate a broader Government activity to establish long-term Government research that would benefit the Nation.

ISS Considerations and the Eventual Future of the ISS Platform

Clarity regarding plans for the ISS and exploration would be beneficial for NASA's ISS International Partners as well. There are common themes across the partnership in considering the future of ISS and exploration, such as:

- Reducing operational costs;
- Offering frequent visible national astronaut opportunities;
- Continuation and continuity of research and technology development activities;
- Balancing LEO and exploration;
- Maturation of commercial opportunities.

The eventual future of the ISS, whether it is transitioning the operations of the ISS platform to private industry, augmenting it with privately developed modules, combining portions of the ISS with a new private platform, or deploying a new free-flying platform and de-orbiting the ISS, should be evaluated against such considerations as:

- Whether alternative platforms for conducting necessary NASA research and technology development are available;
- The cost of continuing ISS and the cost of enabling the development of new capabilities that could meet NASA's long-term LEO needs and the needs of others;
- The interest among NASA's International Partners to extend, change, or terminate the existing ISS Partnership;
- NASA's strategic human spaceflight leadership;
- The potential for different management approaches for the ISS to reduce its operating costs;
- Changes to the current assessment of the technical feasibility of extending the platform beyond 2024;
- The demand outside of NASA in private industry and other Government agencies for LEO research and technology development capabilities;
- The amount of time required for ISS maintenance vs. research time; and
- The ability to add additional international participants, including distributing costs among a wider base.

From a structural integrity analysis standpoint, the ISS platform has significant structural life well beyond 2028 (based on the current assessment period). Many of the ISS modules, particularly the modules launched in the later years of ISS assembly, are likely to have structural life well into the 2030s (see section 4.4).

These considerations should also be taken into account within the broader national policy questions concerning the importance of an ongoing U.S. human presence in LEO, the foreign policy value of international collaboration in space exploration, and the role of the U.S. Government in that ongoing presence.

NASA believes that with the transition approach and near-term activities outlined here, the U.S. will be well positioned in the mid-2020s to continue to be the global leader in human spaceflight, space research and technology development, and will continue to expand commercial markets that directly benefits the U.S.

This approach will put in place the necessary private industry and Government capabilities and activities that will allow for the *ISS Transition Principles* to be continued to be met through a smooth and uninterrupted process and to facilitate a graceful and predictable logical end to the ISS on-orbit platform in the future.

4.0: MAJOR ELEMENTS OF TRANSITION

The following sections highlight several of the major elements of ISS Transition that shape current ISS operations and utilization, as well as the ISS Partnership, and the future of the ISS and LEO.

4.1: NASA'S LONG-TERM LEO REQUIREMENTS

Consistent with the *ISS Transition Principles*, NASA's exploration strategy and the U.S. Government's obligation under the International Partner agreements, NASA has developed the following long-term LEO requirements that are meant to be part of a broader commercial market in LEO where NASA is one of many customers.

Expanding our International Partnerships

With the expectation that NASA will leverage the ISS International Partnerships to expand the U.S. leadership in space from LEO to the Moon and eventually to Mars, it is vital that NASA continue to meet U.S. obligations under the ISS agreements. Additionally, given the expected geopolitical environment in LEO in the mid-2020s, and to expand the U.S. leadership position beyond the current ISS International Partners, NASA intends to support relationships with other space agencies and/or nations that share NASA's goals in LEO and exploration.

Regular LEO Crewed Operations, Including Short and Long Durations

It will remain vital to NASA's mission of exploration and discovery to continue regular crew rotations and operations in LEO. The demands and risks associated with deep space travel will require seasoned and experienced crews who are proficient in the rigors of human spaceflight as well as the operational experience of critical dynamic flight operations such as launches, vehicle proximity operations, docking, and extra-vehicular activity. LEO provides the only cost-effective and viable environment to gain the experience necessary to send crews into deep space.

Additionally, NASA crews can be available to conduct research activities that are consistent with their exploration mission. It is expected that research could also be conducted by private or other Government agency professional astronauts in the future.

Human Health and Habitation System Integrated Performance and Validation

Human health and performance risks during spaceflight derive from five primary stressors: Altered Gravity, Hostile/Closed Environment, Isolation and Confinement, Radiation, and Distance From Earth. The impacts of these individual stressors on health and performance vary with both mission and vehicle design.

Many years of health and performance monitoring coupled with dedicated research facilities and crew participation in LEO research experiments, especially aboard the Space Shuttle, Mir Station, and more recently ISS, have significantly improved our understanding of and ability to mitigate the risks associated with Altered Gravity and Hostile/Closed Environment.

As currently planned onboard the ISS, NASA expects to conclude its Altered Gravity and Hostile/Closed Environment research and countermeasures development by 2024. In addition, NASA also expects to complete its long-duration habitation system/technology demonstrations by 2024 onboard the ISS including the life support system, environmental monitoring, and other systems.

The other three individual stressors, Isolation and Confinement, Radiation, and Distance From Earth, will be very different from our current experience on ISS than during exploration missions, especially those beyond the Earth-Moon system. Combining the elements of spacecraft design and life support systems, with the expected time delay in communications on deep space missions, along with isolation and confinement of an actual on-orbit flight simulation is an essential element for validating countermeasures and integrated system/vehicle performance during long-duration deep space missions. Ideally, these simulations of up to a year in length would be conducted in deep space to also include the effects of radiation as well. However, it may be prudent from an access and overall integrated LEO and exploration strategy to begin these simulations in LEO where access is more readily available. These simulations can also be combined with other NASA requirements as described in this section.

Long-Term Technology/System Development and Demonstrations

In order to continue to be able to operate long-duration deep space systems that are reliable and functional on missions of one-to-three years in duration, NASA will require that the technology and systems that support human health and performance are "life" tested and have the ability to evolve in a real-life test bed environ-

ment. This testbed environment is ideally suited for LEO and longer-duration crew rotations. The human-related systems such as life support and environmental monitoring will always remain critical to the NASA exploration mission as it is key to human spaceflight.

Space Life and Physical Sciences Basic and Applied Research at Current Levels and Capabilities

NASA will continue to require access to a LEO platform to enable exploration and to pioneer scientific discovery for and with other Government agencies, commercial companies, and international partners. NASA will continue to focus research in the highest value areas as guided by the National Academy of Sciences' Decadal Survey and NASA exploration program needs. These areas include research in plant and microbial biology, animal and human biology, fundamental physics research, cryogenics and heat transfer, combustion research, and applied materials research, among others.

The knowledge gained and the researchers trained through this effort will help develop the future commercial workforce and be the foundation of future generations of space technologies, as NASA expands human presence in space and uses this understanding of the behavior of biological and physical systems in space to expand human capabilities.

National Laboratory-Based Research and Technology Development

Just as other national laboratories, such as those run by the Department of Energy, have provided ongoing essential science and technology research assets to the nation, an ongoing microgravity national laboratory capability is needed for use by other Government agencies and academia. Some specific examples are:

- The Department of Defense programmatic expansion of life sciences research, development for Regenerative Medicine and Living Foundries, and activities to advance technology readiness levels for advanced materials, advanced manufacturing, and laser communication initiatives.
- The National Institutes of Health biomedical research focused on human physiology and disease such as recently-sponsored “tissue chips” (or “organs-on-chips”), that will help scientists develop and advance novel technologies to improve human health. Additional discussions with other NIH institutes and centers include the National Cancer Institute (NCI), the National Institute of Aging (NIA), the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS), and the National Institute of Biomedical Imaging and Bioengineering (NIBIB).
- The National Science Foundation’s research in the physical sciences and biomedical systems.

These and other Government agencies, as well as academic institutions, have broadened their engagement in microgravity research and applications, and are expected to have continued needs for a LEO research platform going forward.

Opportunities for Astrophysics, Space, and Earth Science Research.

The infrastructure for maintaining human presence in LEO for longer durations is well-suited to accommodating some investigations in the fields of astrophysics, space and Earth sciences. The power, heat rejection, communication, and scale of platforms that can accommodate humans can also accommodate exterior payloads with compatible requirements, given appropriate forethought in attachment sites and available payload services such as power and communication. This approach has been used now for several years onboard the ISS. This approach is also being applied to the Gateway in cislunar space.

Conclusion

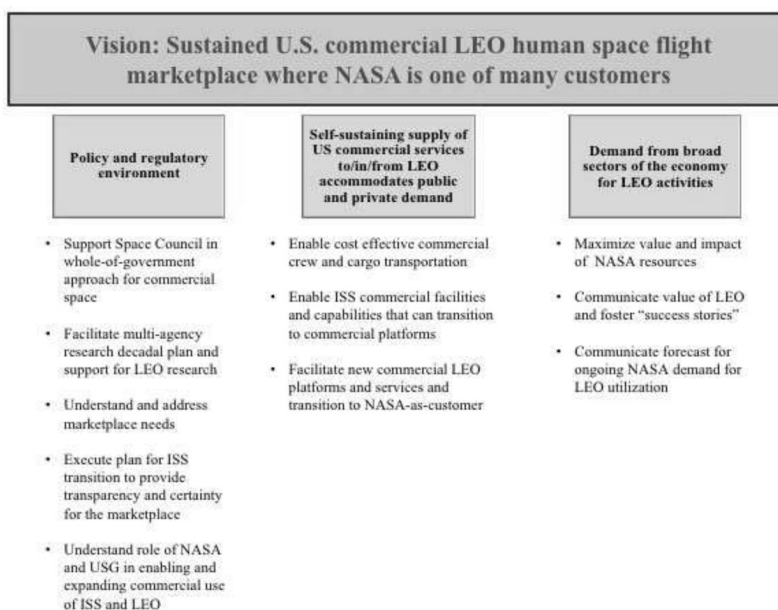
In this post-2025 timeframe, these long-term requirements, while similar to that of the current ISS Program, could be met with various types of modules or platforms that do not necessitate a vehicle (or vehicles) as complex as the ISS. Many of the research activities could be conducted on shorter-duration platforms, similar to the Shuttle, or even crew-tended platforms.

4.2: ENABLING THE DEVELOPMENT OF A COMMERCIAL MARKET IN LEO

NASA’s vision for LEO is a sustained U.S. commercial LEO human space flight marketplace where NASA is one of many customers. The vision includes one or more privately-owned/operated platforms—either human-tended or permanently-crewed—and transportation capabilities for crew and cargo, that enable a variety of activities in LEO, where those platforms and capabilities are sustained primarily by

commercial revenue rather than relying on NASA and the U.S. Government as their main source of revenue as is the case today with the ISS. NASA must also communicate its forecasted needs in LEO to allow the private sector to anticipate that demand in their business cases. With this vision, NASA is able to share the cost of a LEO platform with other commercial, Government, and international users. This allows NASA to maximize its resources toward missions beyond LEO, while still having the ability to utilize LEO for its ongoing needs as described in Section 4.1.

Since 2014, NASA has identified specific goals and initiated key activities to help enable the vision for a sustained LEO human space flight marketplace. This plan has evolved as the landscape has changed, informed by the challenges and progress highlighted above.



Initiatives are organized into three main goal areas—policy, enabling commercial supply, and enabling demand.

Policy and Regulatory Environment

NASA will continue to support the National Space Council's commercial space cross-agency planning. Although other Government agencies are utilizing the ISS National Lab to an increasing extent, NASA would like to facilitate a multi-agency decadal planning initiative for LEO research to further support future LEO platforms from Government users besides NASA. NASA will continue to assess marketplace needs to help facilitate the ability of companies to conduct business. Executing the transition planning for the ISS, along with instituting new commercial activities on the ISS, is important to provide expanded opportunities and certainty for companies proposing new commercial activities.

Self-Sustaining Supply of Commercial LEO Services

The development of a healthy commercial supplier base for LEO activities is critical to NASA's plans. Today, the ISS is already enabling commercial cargo and crew transportation that industry is working to make more cost-effective in the future. Through initiatives such as the Research, Engineering, and Mission Integrated Services (REMIS) contract, NASA is transitioning from historically NASA-provided services for tasks such as payload integration to purchasing those services from a wide variety of commercial suppliers (see Section 4.2.1 for more on REMIS). NASA intends to continue to expand these types of commercial interactions, utilizing more commercial acquisition strategies, and enabling greater commercial use of ISS by offering its unique capabilities while providing Earth-similar laboratory capabilities that ultimately can be transitioned to other platforms. As a first step in enabling Earth-similar laboratory capabilities on ISS, NASA has provided state-of-the-art,

real-time analytical capabilities, such as quantitative Polymerase Chain Reaction (qPCR), utilized standard laboratory processing techniques, and enabled the crew to operate as partners through real-time space-to-ground discussions with the researchers. NASA and CASIS have identified a candidate list of additional hardware and data capabilities including:

- Automated cell-culture hardware with commercial off-the-shelf microfluidic systems;
- Cell-culture hardware with embedded sensors capable of providing information on cell physiology and health status, metabolic flux, or electrophysiological output;
- Expanded capabilities for rodent research;
- Expanded capabilities for additive manufacturing, tissue engineering, and bio-fabrication;
- CubeLab capabilities, including heating and accommodation of chemical reactions;
- Multi-material 3D printing facility, dedicated metal casting facility, and computer-controlled milling capability;
- Self-contained, plug-and-play, remotely-operated printed circuit board and electronics facility enabling in-space manufacturing of conductive materials, biologic material, functional electronic components, sensors, and circuits.

The final initiative in the supply category is to facilitate new commercial LEO platforms and services and transition NASA's needs in LEO to those services once available. In 2016, NASA issued an RFI and received interest in utilizing available ISS ports and other unique capabilities for commercial activities from multiple companies. Since then, the Agency has been assessing the policy, programmatic, and technical impacts of implementing a commercial module on the ISS. Currently, NASA is planning to solicit input from industry for capabilities and services in LEO that could meet NASA's needs as one of many customers. This could include a module on the ISS, free-flyers, or other related capabilities.

Demand from Broad Sectors of the Economy

The final and most critical goal area relates to the development of commercial markets and demand for LEO activities beyond the more "traditional" microgravity research and applications, into broad sectors of the economy. Unless this demand is expanded, future private LEO platforms will likely not be viable without significant ongoing Government support. It is necessary to maximize the value and impact of the ISS today to allow users to explore new microgravity applications and test markets, and communicate those success stories to stimulate broader interest in LEO from non-traditional space users. Finally, NASA must communicate its forecasted future needs for LEO (described in Section 4.1) so that private companies can incorporate expected NASA demand into their business cases.

4.2.1: THE CURRENT LEO ENVIRONMENT

The following section will examine: (1) the current commercial LEO landscape; (2) the challenges and barriers to enabling greater commercial utilization and markets in LEO; (3) the potential commercial LEO markets; and (4) the Commercial LEO Development program.

(1) The Current Commercial LEO Environment

Today, NASA is supporting the development of a commercial space economy in LEO through public-private partnerships to include contracts, and other agreements centered around the ISS platform. Total launches to the ISS equate to 14 percent of the worldwide commercial launch market, with NASA's commercial cargo launches representing 5 percent of total launches.¹ NASA's commercial crew partners, SpaceX and Boeing, have made significant progress toward returning crew launches to the United States by 2019. NASA's commercial cargo partners, Orbital ATK and SpaceX, continue to provide reliable and increasingly timely cargo deliveries to ISS, and the Sierra Nevada Corporation has been added to the fleet under the Commercial Resupply Services-2 (CRS-2) contract. Some of these launch vehicles are now being used for non-NASA customers, and the crew and cargo spacecraft have the potential to support future commercial enterprises as well.

¹FAA Commercial Space Transportation Forecast, https://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/forecasts/

When NASA initiated the Commercial Orbital Transportation Services (COTS) effort, the Agency was in need of U.S. cargo transportation systems for the ISS and the United States had lost almost all of the global market for commercial launch services. COTS successfully addressed both of these issues. NASA is currently purchasing commercial cargo transportation services to and from the ISS and NASA's commercial partners' cost-competitive launch systems have allowed the United States to regain global commercial launch leadership. Since 2005, the year NASA began working with its partners, the U.S. share of the commercial launch market has grown from 9 percent in 2006 to 52 percent in 2016 and continues to increase today. Enabling commercial cargo and payload launch services development through the public-private COTS partnership and the CRS contracts proved to be a benefit to NASA, with both companies—Orbital ATK and SpaceX—financing the majority of their development costs. During the COTS partnership, NASA contributed \$396 million toward development of SpaceX's commercial cargo transportation systems (Dragon spacecraft and Falcon rocket), while SpaceX estimates contributing approximately \$450 million. Likewise, NASA contributed \$288 million towards the development of Orbital ATK's (then Orbital Sciences) system (Cygnus spacecraft and Antares rocket), while Orbital ATK estimates their company contribution to be approximately \$500 million. The COTS effort proved to be cost effective for NASA when compared to traditional development approaches. NASA compared SpaceX's Falcon 9 launch vehicle development costs using the estimated costs of a traditional cost-reimbursement contract versus the COTS milestone-based effort. NASA's models predicted that Falcon 9 development would cost the Government multiple times more using a cost-reimbursement acquisition. SpaceX has indicated that their Falcon 9 development costs were approximately \$300 million.

In addition to the cargo and crew transportation initiatives, NASA is leveraging the ISS to enable other commercial capabilities. As the demand for space research and development projects increases, numerous commercial companies are developing, operating, and maintaining their own commercial payload facilities on the ISS. These organizations operate their facilities internally and externally on Station and provide users with more choices to address unique research needs; they are the pathfinders for a marketplace in LEO. Many of these organizations have used their own resources to invest in on-orbit research and development facilities, reducing the risk for the Federal sector to develop these facilities and services. These companies find customers through CASIS and their own business development efforts to enable the research and development for customers CASIS has developed. When these companies are able to provide capabilities that meet NASA needs, the Agency may contract with them as one of potentially many customers utilizing their unique services. Currently, a number of companies are providing services on-orbit, including BioServe, Made In Space, NanoRacks, Space Tango, TechShot, and Teledyne Brown Engineering.

Through the ISS Research, Engineering, Mission and Integration Services (REMIS) contract, NASA has begun to transition from a model where NASA provides its own payload integration, engineering development, and sustaining services to one where those services can be purchased from one of many commercial providers through a competitive process. This contract was developed to allow companies to slowly take over historically governmental functions in a step-wise manner using their commercial approaches to doing business. By allowing industry to take over these functions, companies will develop more efficient approaches that will be cheaper and further reduce the costs of doing business in space.

The ISS National Lab, managed by CASIS, has been a key enabler of the expanded commercial use of LEO. Since 2011, more than 200 ISS National Laboratory research projects have been flown to the ISS—ranging from developing new drug therapies, to monitoring tropical cyclones, to improving equipment for first-responders on the ground, to producing unique fiber-optics materials. In the last several years, at least 50 percent of the ISS National Lab projects were new-to-space customers, and more than 50 percent involve commercial users (*i.e.*, for-profit companies). The ISS National Lab is currently opening up the possibilities of the Station research environment to a diverse range of researchers, entrepreneurs, and innovators that could create entirely new markets in space. These areas include, but are not limited to, drug delivery systems, crop science, regenerative medicine, reaction chemistry, materials science, fluid dynamics and transport phenomena, on-orbit production and microgravity-enabled materials, protein crystal growth (also known as macromolecular crystal growth), Earth observation, and remote sensing. These activities are part of a young portfolio of non-NASA projects that are beginning to benefit from increased access to the ISS as well as shorter timeframes from project concept to implementation on the ISS. The ISS National Lab portfolio's current positioning forecasts growth in the next ten years in areas such as cell and gene ther-

apy, 3D bio-printing scaffolds, and aerospace projects using the LEO platform to raise technological readiness levels of next-generation LEO and beyond infrastructure systems.

CASIS has developed a successful sponsored-program model that attracts third-party funding from private industry and other Government agencies to solve significant problems or address target challenges. Successful sponsored programs include those by Boeing/Mass Challenge, Massachusetts Life Sciences Center, NSF fluid dynamics and combustion, and NIH's National Center for Advancing Translational Sciences (NCATS) Tissue Chips in Space program. The significance of this model is the shift from 100 percent NASA-funded projects to an ability to attract third-party funding. Time is needed for the private sector to develop and grow new markets and opportunities in LEO using the ISS and to be willing to invest greater amounts of capital into such efforts.

These initiatives represent great progress toward enabling a commercial space economy around LEO; however, today the non-NASA market demand is not able to offset the costs without significant Government support. The next sections will discuss the ongoing challenges and projected commercial market landscape.

(2) Challenges

Through Requests for Information (RFIs) and other interactions since 2014, including workshops with external stakeholders (most recently in August 2017), industry has identified the following challenges and barriers to achieving the vision of a self-sustaining marketplace in LEO:

Uncertainty Concerning Future Availability and Uses of ISS/LEO Platforms

Industry needs a clear statement of U.S. policy and commitment regarding the creation and support of an economy in LEO. Industry wants to understand what NASA's transition plan is for ISS and LEO beyond 2024. Companies need concrete assurances that they can plan activities in LEO beyond the ISS program, and that the U.S. Government is committed to being involved in a commercial replacement, including whether it is as a regulator and customer, or other role.

Cost of Transportation/Access

Today, the \$1.7 billion annual cost of transportation to the ISS represents over half of the total ISS budget. NASA's current policy of providing transportation for all payloads has been a significant incentive to attract new users to the platform. It is uncertain whether these and future users would be able to afford their own access costs. The U.S. commercial launch providers are continuing initiatives to lower costs through innovations including reuse of components; however, launch costs continue to be substantial. Access to affordable and reliable transportation also has broader implications, such as ability to operate and manage any such ISS/LEO platforms.

Government Acceptance of the Premise that Commerce has Value

ISS activities shouldn't be limited to only those activities that are considered the "best and highest" uses of the ISS National Laboratory. U.S. companies seek authorization to brand, advertise, promote tourism, and manufacture commercial products on government platforms like the ISS that otherwise have little intrinsic value from a national perspective. In the view of U.S. industry, commercial companies should be able to conduct business on ISS as long as those activities are safe, legal, and ethical. There also needs to be a discussion with the ISS International Partners on the implications of broadened use in order to ensure consensus and effective implementation. This is being addressed in the development of the ISS commercial use policy.

Ability of Government Astronauts to Participate in Commercial Activities

Appropriated funds limitations, absence of statutory promotion authority and Federal ethics rules affect the ability of Government employees to participate in certain commercial activities being sought by companies, especially where endorsement or advertising are involved. This limits the types of activities that can be performed and some private revenue-generating activities. NASA has received expressions of interest to enable these types of activities as a means to an end for development of a commercial LEO marketplace.

Lack of Current Commercial Pricing Structure

In order to transition to a more commercial model where commercial users pay for transportation and other services, NASA must develop a pricing structure for ISS services that does not exist today.

Flexibility in Contracting and Public/Private Partnership Agreement Mechanisms

Industry sees funded Space Act Agreements and other non-Federal Acquisition Regulation agreement mechanisms as preferred options for stimulating a new commercial space capability and would like NASA to expand their use as part of any LEO commercialization efforts.

Recognition of Intellectual Property (IP) Rights

NASA and the Department of Energy are the two principal Federal agencies that, pursuant to statute, take title to contractor inventions made in performance of their duties under their contract (including recipients of cooperative agreements, like CASIS, and grants) [51 U.S.C. § 20135]. Today, this title-taking requirement is seen as a barrier to private industry seeking to participate with NASA in research and development activities on the ISS National Lab because NASA takes title to any inventions made by such entities in the course of work funded by NASA.

In 2017 NASA improved the ability of private industry to retain title to their inventions. NASA granted a patent waiver (*i.e.*, a “Class Waiver”) that allows commercial institutions with user agreements to retain title to their inventions. Specifically, the waiver applies to CASIS’ user agreements with commercial institutions that: (1) receive access to the ISS National Lab under CASIS’ cooperative agreement with NASA, but (d) do not receive any NASA funds from CASIS under the user agreement. This change is reflected in the patent rights clause in CASIS’ cooperative agreement. NASA also ensured, through the data rights clause, that parties to user agreements receive unlimited rights to data produced under the agreement and need only share such data with the Government and CASIS in limited situations. It is anticipated that the patent waiver and revised data rights clause will spur greater interest in performing privately-funded research and development work on the ISS National Lab.

In addition to NASA’s grant of the “Class Waiver,” the Agency has also sought a legislative proposal that would further maximize the intellectual property rights retained by ISS National Laboratory users. Although users may retain title to their inventions under the recently approved “Class Waiver,” the Government is still required under the Space Act to retain a license in such inventions for Government purposes. Therefore, while the U.S. Government purpose license does not permit any transfer of the inventions to commercial entities for commercial purposes, it continues to be identified by industry as a barrier to commercial research and development because of a fear that the license could result in their competitors gaining access to their sensitive and/or proprietary information. The proposed legislation would exempt in totality inventions arising from use of the ISS National Laboratory from NASA’s title taking authority under the Space Act. ISS National Laboratory users would thus have immediate and full ownership of their inventions without NASA and other Federal agencies utilizing those commercial inventions for their own programs and activities. NASA supports this legislative proposal as a means to facilitate greater use of ISS National Laboratory and LEO commercialization.

(3) Potential markets

As non-NASA utilization of the ISS National Lab and interest in LEO continues to expand, some initial assessments of potential revenue-producing activities have been conducted by CASIS, NASA, and the Science and Technology Policy Institute (STPI—see Section 4.3). Based on these preliminary assessments, the potential activities that could generate revenue for a crew-tended or permanently-crewed platform in LEO can generally be summarized in the following categories:

- Human habitats as a destination for private space flight participants, including Government-sponsored astronauts from the United States and other Partner or non-Partner nations;
- Activities supporting the satellite sector, such as on-orbit assembly of satellites;
- Manufacturing products and services for use in space and on Earth;
- Research and development, testing, and Earth observation;
- Media, advertising, and education.

Estimates for revenues from these activities vary widely depending on many assumptions—operating costs of the platform, revenue models, magnitude of forecasted demand, future transportation costs—making it difficult to make projections as to the viability of these or other potential markets that might emerge.

These types of assessments will continue to be updated as markets and assumptions mature over time. Though NASA is seeing an increase in new users that suggests a promising trend, today’s projections conclude that it is unlikely that these activities will have matured to the point where they can sustain a private platform

and their own transportation costs to LEO by 2024 without significant ongoing Government support.

(4) The Commercial LEO Development Program

Through the proposed Commercial LEO Development program, NASA will support commercial partner development of capabilities that the private sector and NASA can use. Efforts will focus on enabling, developing, and deploying commercial orbital platforms and user demand capabilities, with a goal towards ensuring that the U.S. has access to an orbital platform on which to conduct research and develop new technologies.

To achieve the Commercial LEO Development program's goals, its initial activities may include studies on the transition of ISS and other platforms in LEO, risk reduction activities to begin the development of capabilities that could satisfy NASA's needs in LEO, or the development of private platforms or modules attached to the ISS or free-flying in LEO. \$150M has been requested in FY2019 for these activities. This mechanism will allow interested parties to specify what support they desire from NASA, what commercial opportunities they are pursuing, and viability of private industries business case. This could potentially include options such as: (a) access to a port on ISS; (b) access to NASA's experience and capabilities through its unique workforce with expertise in the design, construction, launch, operations, and/or utilization of orbital platforms; and (c) financial support provided through the Commercial LEO Development program. As a companion activity to this program, NASA will develop a policy that ensures that NASA or ISS National Laboratory activities do not compete with the capabilities provided by commercial LEO platforms. In the longer term, activities currently supported by NASA and the ISS National Laboratory could be fully transitioned onto these new platforms once available. The Commercial LEO Development program will allow private industry to experiment with commercial activities and demonstrate the viability of commercial human spaceflight activities.

The Commercial LEO Development program will advance the Nation's goals in LEO and exploration by furthering development and maturity of the commercial space market to enable private industry to assume roles that have been traditionally Government-only, and to potentially realize cost savings to the Government by leveraging private industry innovation and commercial market incentives.

4.3: SCIENCE AND TECHNOLOGY POLICY INSTITUTE ANALYSIS

An initial assessment was conducted in 2017.

The Science and Technology Policy Institute (STPI), under the direction of OSTP, conducted an initial assessment in 2017 of the viability of a private LEO platform. An executive summary of the full report ("Market Analysis of a Privately Owned and Operated Space Station," by Keith W. Crane, Benjamin A. Corbin, Bhavya Lal, Reina S. Buenconsejo, Danielle Piskorz, Annalisa L. Weigel, February 2018) follows:

The Administration has set the goal of transitioning the International Space Station (ISS) to a model where NASA is one of many customers of a non-governmental enterprise that owns and operates a human-tended space station in low Earth orbit (LEO). This transition poses important questions about continued U.S. human presence in LEO. Is the private sector likely to take over and run ISS on a commercial basis? Or will governments, including that of the United States, continue to be the primary owners, operators, and customers for space stations? The purpose of this evaluation is to determine whether a future (i.e., 2025 and beyond) private space station could generate sufficient revenues from a variety of possible activities to cover the operations and capital costs of such an endeavor.

Methodology

We assumed that a private space station would be wholly owned and operated by private parties who would decide the station's capabilities, the markets it would serve, and the prices it would charge for its services. We identified revenue-generating activities, envisioning the station as an industrial park in space where entities rent parts of the station for their activities. We then generated "high" and "low" estimates of revenues that the space station could earn by leasing space or providing services in support of these activities, corresponding to different sets of revenue-driving assumptions, although neither should be considered a strict lower or upper bound. We generated these estimates using inputs from interviews with over 70 experts, by examining current ISS activities, and by drawing on other sources to determine likely market size in order to develop separate cost methodologies for each posited activity.

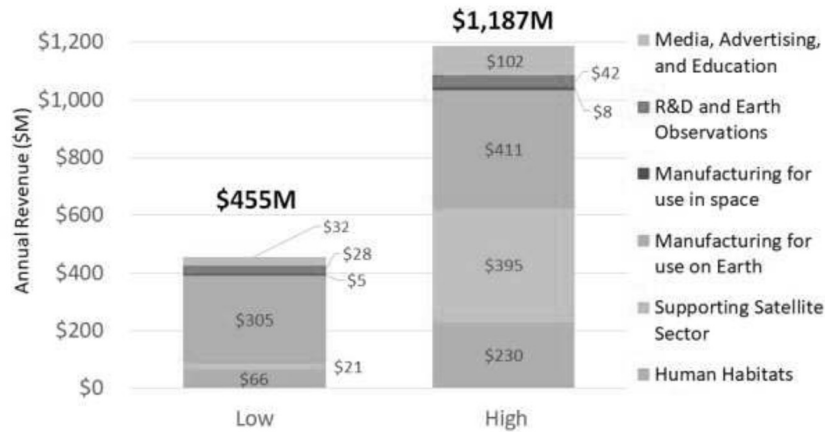
The analysis has had to incorporate a number of cost assumptions for the 2025 and beyond timeframe. Some of the most critical of these are: cost of launching an

astronaut, about \$20 million; encapsulated cargo, about \$20,000 per kilogram (kg); and propellant transport, \$5,000 per kg. These represent considerable savings over market prices when research for this project was conducted, between May and October 2016.

Potential Private Space Station Activities and Revenue Streams

STPI identified 21 separate types of activities that could generate revenues on a private LEO space station. These fell into five broad categories: (1) Habitats for space flight participants or government astronauts, (2) activities supporting the satellite sector, especially on-orbit assembly of satellites, (3) manufacturing products and services for use in space and on Earth, (4) research and development (R&D), testing, and Earth observation, and (5) Media, advertising, and education.

The “low” estimate for total annualized revenues from activities conducted on a space station is about \$460 million, and the “high” estimate is roughly \$1.2 billion. Manufacturing in space is the largest contributor to overall revenues, accounting for nearly 35 percent of the “high” estimate and more than half of the “low”. Potentially profitable manufacturing of exotic optical fibers drive these revenues. Revenue from satellite support is 30 percent of total revenues in the “high” estimate.

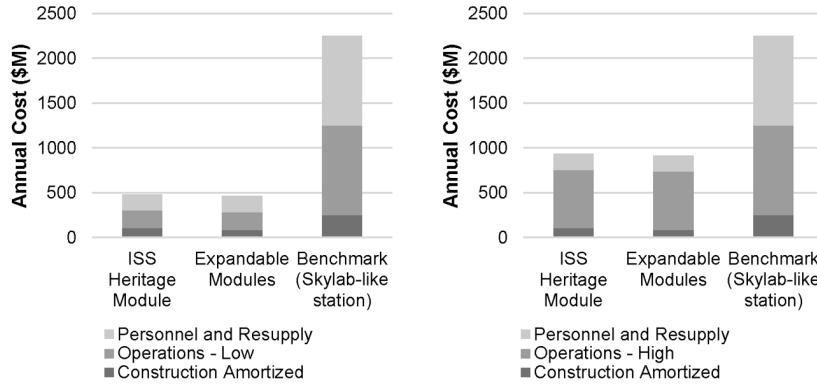


Distribution of Projected Annual Revenues for the Space Station

The large difference between the “high” and “low” estimates reflects the highly tentative nature of the cost estimates. Our methodology ruled out products and services such as growing human organs in space that we believe are more than a decade away from reality. Other challenges make our projections particularly uncertain, such as competition from other nations, new technology developments that negate the need for production in microgravity, and uncertain market growth patterns. While the projections are per force speculative, they do provide empirically-based assessments of almost all of the activities that have been discussed as potential revenue sources for a privately owned and operated space station.

Private Space Station Potential Costs and Net Profits

We next examined general types of space station configurations to determine ones that might best generate revenues. We developed cost estimates for a station constructed from ISS-heritage modules and one constructed from expandable modules. We also used a publicly available estimate of the costs of a Skylab-like station as a benchmark. There are three elements in the breakdown of the annual cost estimate: (1) the costs of designing and constructing the station (amortized over 10 years), (2) costs of operations, and (3) costs to the station owner of transporting their astronaut employees to and from the station and resupplying them. Given the lack of consensus among our interviewees, we generated a low and a high estimate for operations costs.



Low (left) and High (right) Estimated Annualized Costs of Private Station Concepts

Neither estimate of annual revenues covers the estimate of annualized costs for the expensive benchmark station. Out of the four boundary scenarios, only in the high-revenue low-cost estimate would the station be profitable, as shown in the diagram below. Venture capitalists interviewed for the project noted that the projections of revenues and costs are so uncertain that they would have little interest in financing a space station until projected revenues show signs of actually materializing.

Cost	High	Low Revenue \$455 M High Cost \$2,250 M Annual Loss = -\$1,795 M	High Revenue \$1,187 M High Cost \$2,250 M Annual Loss = -\$1,063 M
	Low	Low Revenue \$455 M Low Cost \$463 M Annual Loss = -\$8 M	High Revenue \$1,187 M Low Cost \$463 M Annual Profit = +\$724 M
		Low	High
		Revenue	

Annualized Cost and Revenue Estimates for a Private Space Station

A sensitivity analysis on the results showed launch costs to be the major driver of both revenues and costs. If launch costs were cut in half, either as a result of a technology breakthrough or a government subsidy, the estimates of revenues for the low-cost station would increase by 23 to 53 percent, for the "high"- and "low" scenarios, respectively, and costs would decrease by 16 percent. If the government subsidizes launch costs entirely, revenues for a low-cost private space station would go up by 46 to 106 percent, for the "high"- and "low" scenarios, respectively, and costs would decrease by 33 percent.

Federal Government Participation in the Private Space Station Market

The Federal Government may wish to plan in advance about how it would engage in the emergence of a private space station or space stations, to potentially reduce market, financing, regulatory, policy, and technology risks to operators and their in-

vestors. Options that could be used separately or together to assemble a strategy for government participation include:

- **Early stage investment through a public-private partnership:** A private space station is inherently risky. The U.S. Government can participate as an investor in a public-private partnership with a space station owner and operator to ensure that the project comes to fruition and also to influence the design of the station to ensure that it fills NASA's needs. The private partners need not be commercial entities; they could be a non-profit consortium of universities or other organizations with the ability to raise private funds.
- **Advance purchase or lease agreements:** Through advance purchase agreements and advance long-term lease agreements for a private space station, the U.S. Government could provide an early customer commitment to secure a guarantee-of-service at more favorable conditions than purchases at market prices after the station is completed. These policy instruments shift the outlays of expenditures closer to the time of delivery of the product or service than would a direct investment in the station.
- **Direct purchases of space station services:** The U.S. Government could choose to wait until a space station is completed and operating, then rent space for R&D or purchase other services provided by the station as needed. At that point in time, purchases of services would be at market prices that would likely be higher than prices provided for advance purchases. Services may also be subject to availability constraints; however, purchases on these conditions would offer the government flexibility, as the government would have made no commitment in advance to purchase services.

4.4: UTILIZING THE ISS TO ENABLE HUMAN EXPLORATION OF THE SOLAR SYSTEM

Through its Exploration Campaign, NASA will lead an innovative and sustainable program of human and robotic exploration with commercial and international partners to enable human expansion across the solar system, and to bring new knowledge and opportunities back to Earth. Beginning with missions beyond LEO, the U.S. will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations. The delivery and return of astronauts and cargo to and from ISS is measured in hours, but any journey to Mars will take many months each way, and early return is not an option. Deep space crewed missions will not have regular access to the Earth's resources or the ability to rapidly return to Earth if a system fails. This is an entirely different operating regime, not just for physical access but also for communications with Earth-based teams. Astronauts in deep space must be more self-reliant and spacecraft systems and operations must be more automated to operate safely. Habitation systems must become more efficient and more reliable for safe, healthy, and sustainable human exploration. Furthermore, crews must be protected from the unique hazardous environments of deep space. Some deep space systems may have to remain dormant for years in preparation for crew, and must remain in operational order. Overcoming these challenges will be essential for deep space exploration.

The Agency has developed a phased approach for deep space exploration, starting with ISS and progressing to cislunar space, the lunar surface, then to Mars and beyond. NASA is already well underway in executing this approach. Aboard the ISS, NASA and its partners are conducting targeted research to improve understanding of how humans adapt and function during long-duration space travel. Current and planned risk-reducing investigations include bone and muscle loss studies, understanding the effects of intracranial pressure changes and fluid shifts, monitoring immune function and cardiovascular health, conducting nutritional studies, and validating exercise protocols. With these studies, NASA explores the physiology of the human body, preparing for long-duration spaceflight and supporting development of terrestrial drugs and therapeutic practices. NASA and its partners' activities on the ISS are achieving key milestones and enabling an expansion to early pioneering missions in cislunar space.

On ISS over the coming years, NASA will also demonstrate many of the capabilities needed to maintain a healthy and productive crew in deep space. Currently manifested or planned experiments and demonstrations include improved long-duration life support, improved environmental monitoring technologies, advanced fire safety equipment, next-generation spacesuit technologies, advanced avionics and autonomy, high-data-rate communications and precision navigation, in-space additive manufacturing, advanced exercise and medical equipment, and radiation monitoring and shielding.

Specific systems and capabilities under development on ISS include:

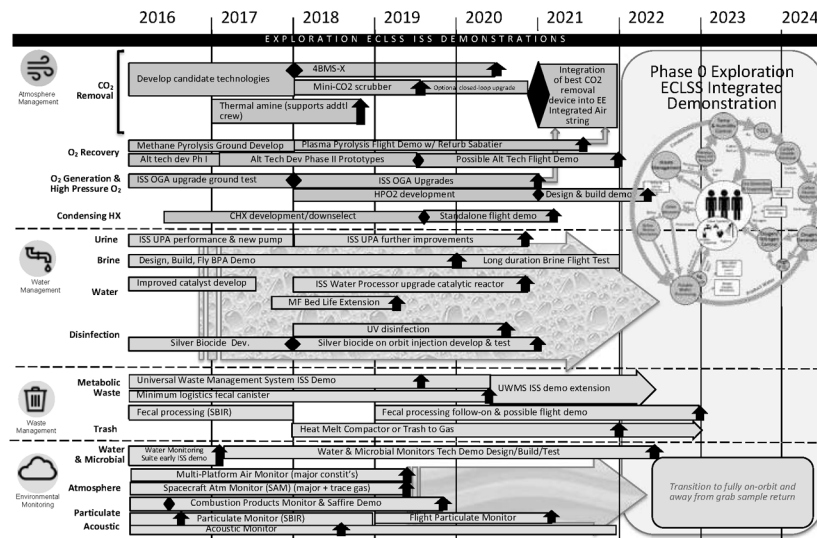
Environmental Control and Life Support Systems (ECLSS) and Environmental Monitoring Leveraging the ISS, NASA is focused on demonstrating advanced capabilities for robust and reliable ECLSS, which must operate for up to 1,100 days with minimal spares and consumables. Water and oxygen for human exploration in deep space will need to be launched with the crew, recycled from the spacecraft's atmosphere and astronauts' waste, or made using the resources of the destination—such as water ice on Mars. Missions into deep space will not have Station's resupply capability, so improvements to recycling processes and technologies are needed to fly long-duration missions. The Station's current system recycles about 90 percent of the water and about 47 percent of the oxygen in the spacecraft while disposing of the crew's solid waste and the briny liquid waste left over from recycling. Regular resupply missions to the orbiting outpost supplement the unrecovered water and oxygen and provide replacement components for those that fail on the system.

To reach a water recovery goal of 98 percent, for example (in comparison with ISS' current recovery capability of approximately 90 percent), NASA will test new technology to reclaim additional water from the urine brine and process for reuse. NASA is also planning upgrades to improve the water recovery system reliability and reduce maintenance, including an improved catalyst for the water processing assembly.

To reach a goal of greater than 75 percent recycled oxygen for deep space missions, NASA is investigating methods that involve the reaction of hydrogen and carbon dioxide to produce solid carbon and water, or acetylene and water. These candidate technologies go beyond the current system on the Station that reacts carbon dioxide and hydrogen to produce methane and water, and would increase oxygen recovery to between 75 and 100 percent. The resulting water is split into breathable oxygen for the crew by the oxygen generation system, and the hydrogen is recycled back to react with more carbon dioxide.

Methods to manage and reduce metabolic and non-metabolic solid waste will also be demonstrated on ISS. A new Universal Waste Management System (UWMS) will be added to the current Russian commode. Technologies to compact, stabilize, and recover useful resources from trash, methods to repurpose logistical packing materials such as cargo bags and foam, and a simple laundry system will also be demonstrated.

Over the next five years, NASA will install a series of exploration ECLSS demonstrations on ISS, culminating in an integrated demonstration of an exploration ECLSS system on the Station for two to three years to prove reliability. Additionally, ISS will conduct demonstrations of Environmental Monitoring systems that detect potentially hazardous materials in the atmosphere and water as well as combustion products. This will enable a transition away from sample return to fully on-orbit environmental monitoring.



Communications and Navigation

Currently, Mars robotic rovers have data rates around two million bits per second, using a relay, such as the Mars Reconnaissance Orbiter. Transmission from the ISS is two orders of magnitude faster, at a rate of 300 million bits per second. Future human Mars missions may need up to a billion bits per second at a range many times greater than the distance to ISS, requiring laser-based communications, in addition to radio, to reduce weight and power. In addition, disruption and error-tolerant interplanetary networking and improved navigation capabilities are required to ensure accurate trajectories and precision landing. The Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT), installed on ISS in June 2017, is one such capability that will enable improved navigation. It will test—for the first time in space—technology that relies on pulsars as navigational beacons. The technique may eventually guide human exploration to the distant reaches of the solar system and beyond. Additional details on communications and navigation technology will be included in the Space Communications plan (called for in Section 304(a) of the NASA Transition Authorization Act of 2017) to be provided to Congress in spring of 2018.

Advanced Avionics, Software, and Autonomy

In order to support extended human exploration to the Moon and beyond, a more integrated and autonomous vehicle will be needed, requiring more advanced avionics (computers, memory, networking, and software). As these systems and associated architecture are developed, systems will be flown on ISS to test and verify the capabilities in space. The advanced avionics will also be used to connect other new systems (e.g., ECLSS, or power), such as the Lunar Gateway and future interplanetary vehicles.

Future vehicles will need to operate with no crew and limited ground control. To achieve this, more comprehensive and advanced autonomous systems, including vehicle health monitoring and reconfiguration, need to be developed and tested. The ISS will serve as a testbed for these systems. Initially, new autonomous system technology is being tested using existing ISS computers. As these advanced avionics architectures and systems are developed, the enhanced computing capability will be used to test and verify more advanced autonomous operations. In addition, the crew will need more advanced tools to assist them, such as planning assistants and augmented reality for troubleshooting and maintenance. As these are being developed, they will be tested on ISS to ensure they provide the astronauts with the required capabilities. Early versions of some of these tools are being tested on ISS now; this will grow in number and complexity as NASA develops more comprehensive or diverse tools and some of these will require the advanced avionics.

Exploration Extravehicular Activity

Human explorers will require deep space exploration Extravehicular Activity (EVA) suits for use in cislunar space and beyond. Such suits must be available to provide for exploration of deep space destinations and environments, and for contingency EVAs in transit. The environments and logistics demand a different design solution than met by the current flight suit. New EVA systems must supply basic biological needs during spacewalks, provide protection from hostile environments, and enable comfort, flexibility, and dexterity to support human exploration and investigation of new worlds. Advanced space suit design, manufacture, and operation must address a wide range of considerations NASA has identified in recent years. For example, advanced space suits will operate at higher suit pressures to reduce EVA prebreathe and risk of decompression sickness. Filling consumables at higher pressures reduces the need to return exploration suits to Earth for servicing after contingency events have drained secondary oxygen tanks. High pressure oxygen generation systems will be demonstrated on ISS to address this requirement. Near-term planned EVA technology demonstrations on ISS include testing to advance the technology readiness level of the Solid Water Membrane Evaporation (SWME) system to provide cooling for the next-generation spacesuit. More details on the challenges associated with EVA in deep space environments and NASA's planned EVA capability development efforts can be found in the Advanced Suit Capability Plan provided to Congress in June 2017.

Fire Safety

Whether traveling through interplanetary space or on the surface of another planet, the habitat must detect and stop a fire while protecting the crew, and sustaining only minimal, if any, damage. Current systems onboard ISS rely upon large carbon dioxide suppressant tanks and have no fire cleanup capability other than depressurizing and re-pressurizing the cabin atmosphere. Deep space exploration systems require a unified fire safety approach that works across small and large architecture elements.

Early detection is key to protecting the crew and vehicle. The ISS uses smoke detectors to spot the presence of any potential fire-initiated problems. Advanced smoke detectors—about the size of a small tissue box—are under development for NASA's Orion spacecraft and eventual deep space habitats. They will be placed in the vehicle's ventilation system and if a fire is detected, the spacecraft's fire suppression systems will extinguish it. Additionally, a non-toxic portable fire extinguisher is being developed and tested on ISS to provide additional fire suppression capability.

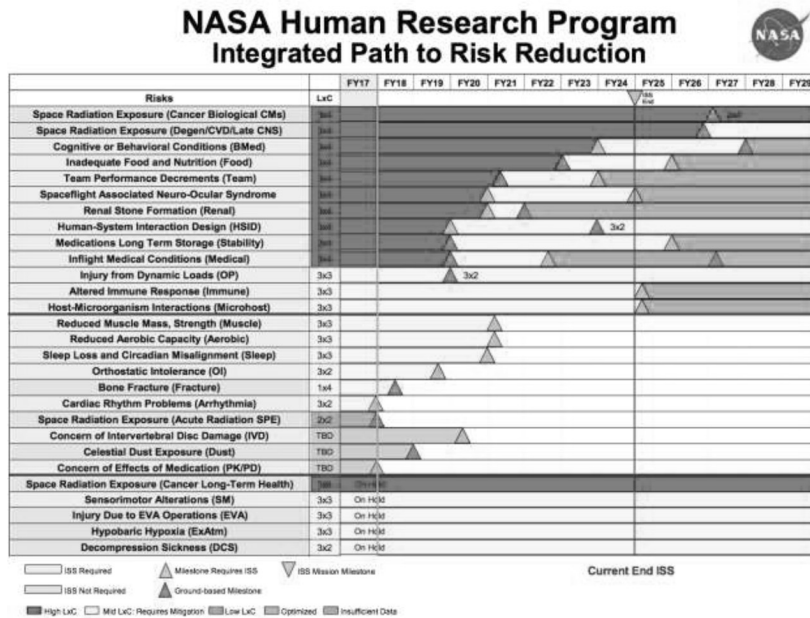
The real danger to astronauts is not necessarily fire itself but the gases produced during combustion, including carbon monoxide, carbon dioxide, hydrogen fluoride, hydrogen cyanide, and hydrogen chloride. NASA is developing a filtering cartridge dubbed the "smoke-eater" to neutralize and remove these compounds. The smoke-eater will be used in the spacecraft's atmospheric cleanup system, and a smaller version will be used in an emergency crew mask that contains its own air supply. Demonstrations of the unit will occur during the Spacecraft Fire Experiment (SAFFIRE) series of investigations that NASA has been executing aboard Orbital ATK's Cygnus vehicles after they depart the ISS. Through these experiments, NASA will gather valuable data on how combustion gas and fire dangers spread in a spacecraft and how the vehicle's detection, suppression, and cleanup technologies respond. Computer models will be developed from that data, enabling prediction of how the fire will propagate in a spacecraft and how the cleanup will go.

Crew Health and Performance

Long-duration exploration-class human missions, including Mars-duration missions of up to 1,100 days, introduce new and increased concerns for human safety, health, and performance. NASA is conducting scientific research needed to supply the evidence base for both technological and operational countermeasures to best address these risks. Human research on ISS includes assessments of devices, consumables/logistics, and operational procedures for the use of these capabilities in a representative microgravity environment in order to supply appropriate solutions to meet the health, safety, and performance challenges of long-duration exploration class missions. Technological and operational interventions and countermeasures that mitigate risk for long duration, exploration class missions include those which (i) optimize adaptation of the individual and crew to the space environment, and maintain emotional well-being, motivation, social cohesion, communication, morale, and productivity; (ii) support prevention, monitoring, diagnosis, treatment, and long term management of crew in-flight health conditions; including those induced or exacerbated by mission characteristics *e.g.*, microgravity and radiation influenced conditions, and long-duration confinement with limited communications beyond the

crew; and, (iii) ensure that the habitat environment design, its ambient environment, architectural affordances, and crew information and communication technologies support task performance requirements and general safety and habitability requirements for crew.

The Integrated Path to Risk Reduction (iPRR) displays the long-range, strategic research plan and schedule and contains a top-level summary of all the risks to the human system, research tasks necessary to close the gaps in our knowledge of these risks the logical sequence and timing of significant tasks, milestones (such as gap closure), and completion of major deliverables. The current version of the iPRR is maintained at <https://humanresearchroadmap.nasa.gov>. A simplified version is shown below.



Human Research on the ISS focuses on reducing the risks of health and performance problems in future exploration missions. Research is prioritized to maximize the productivity of ISS resources.

Radiation Protection

Outside the Earth’s magnetic field, crew and electronics are exposed to increased high-energy particles, including constant exposure to galactic cosmic rays and infrequent—but potentially deadly—solar particle events. These high-energy particles can reduce immune response, increase cancer risk, and interfere with electronics. NASA’s HRP is developing methods and technologies to protect, mitigate, and treat the effects of various types of radiation on the crew and their exploration systems. Installed on ISS in December 2016, the Fast Neutron Spectrometer (FNS) investigation studies a new neutron measurement technique that is better suited in the mixed radiation fields found in deep space. Future manned and exploration missions will benefit from clearer, more error-free measurement of the neutron flux present in an environment with multiple types of radiation.

Logistics and In-Space Manufacturing

Living in deep space away from the frequent resupply enjoyed by ISS crews will require NASA to reduce, recycle, reuse, and repurpose materials. NASA is investigating long-wearing clothing and laundry capabilities to replace the current practice of disposing of cotton clothing. The Agency is also investing in tools to repurpose packaging materials for use as feedstock for in-space manufacturing of items such as replacement parts, science equipment consumables, short-lifespan hygiene equipment, and other tools. NASA’s in-space manufacturing objective is to develop and test on-demand manufacturing capabilities for fabrication, repair, and recycling dur-

ing deep space exploration missions. NASA is leveraging the significant and rapidly-evolving terrestrial technologies for on-demand manufacturing, adapting technologies to the microgravity environment and operations. Technology demonstrations on board ISS will lead to development of an integrated “Fab Lab” facility with the capability to manufacture multi-material components (including metal tools and electronics), as well as automation of part inspection and removal that will be necessary for sustainable exploration opportunities.

4.5: BENEFITS TO HUMANITY

The success of the ISS as a research platform is measured, in part, in traditional scientific terms such as number of scientists using the platform, number of experiments completed, and number of scientific publications and their impacts. With the completion of the U.S. On-orbit Segment (USOS) of ISS in 2011 and the installation of its planned suite of science instrumentation, the academic community has given research on the ISS a new priority. Participation in NASA solicitations for ISS research continues to grow, with proposals for research projects submitted by leading research universities across the United States. Data from previous experiments on the ISS is now available online for scientists to study.

The scientific rationale for the use of ISS for research and the potential exploration and terrestrial benefits is outlined by the National Academies of Science in their 2011 decadal survey—“Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era.” NASA has completed a midterm review with the National Academies of the implementation of this survey. Of special interest to the Nation are those areas where knowledge gained on the ISS goes beyond the scientific literature to have a direct impact on the lives of people here on Earth. All serve as examples of LEO platforms’ potential as a groundbreaking research facility. Through advancing the state of scientific knowledge of Earth, looking after human health, developing advanced technologies, and providing a space platform that fosters commercialization, these benefits will drive the legacy of Station as its research strengthens economies and enhances the quality of life here on Earth for all people. Below are some benefits that have come from ISS research in the area of human health, Earth observation, innovative technologies, and space commerce. Details of the highlights listed below are tracked in a triennial international publication, *ISS Benefits for Humanity*, currently in its 2nd edition, with a 3rd edition under development.

Human Health

Understanding the Acting Mechanism of Osteoporosis Treatments: Biotech and pharmaceutical companies are using mouse models during spaceflight as a medium to study their drugs and do preclinical work that is important for Food and Drug Administration (FDA) approvals. Industry partner Amgen tested three drugs (two for bone loss, one for muscle atrophy) that were under development on Space Shuttle missions to ISS. One of these drugs was Prolia®, which came to market in 2011. CASIS has partnered with Novartis and Eli Lilly, who are also conducting research using mice on ISS as part of their development cycles for other drugs to treat muscle wasting and bone loss.

New Drug for Duchenne’s Muscular Dystrophy in Clinical Trials: Japanese scientists, through JAXA, crystallized a human prostaglandin D2 synthase-inhibitor complex (H-PGDS/HQL-79 complex) on ISS, identifying an improved complex structure and an associated water molecule that was not previously known. The H-PGDS protein has been shown to play a critical role in the formation of Duchenne muscular dystrophy—the most prevalent genetic form of muscular dystrophy, impacting up to 1 in 3,000 boys globally. As a result of this discovery, a new drug was developed that was successfully tested in Phase 1 human clinical trials and is now being tested in Phase 2 clinical trials.

Improving the Delivery of FDA-approved Immunotherapy: KEYTRUDA® is an FDA-approved drug from Merck that is a monoclonal antibody (a large biological molecule or biologic) used in cancer immunotherapy which was crystallized on ISS. Crystallizing the protein allows Merck scientists to understand how it functions to improve treatment for patients on Earth. Crystallizing these monoclonal antibodies enables a method for delivering large doses with injections, rather than intravenously, and improves methods for storing monoclonal antibodies for extended periods.

Robotic Surgery Applications: The development and use of the robotic arm for space missions on the Space Shuttle and the ISS by CSA has led to the world’s first MRI (Magnetic Resonance Imaging)-compatible image-guided, computer-assisted device specifically designed for neurosurgery. This technology, called Irmis®, has also

been applied to develop the world's first robot capable of performing surgery inside MRI machines. It is also being applied in the design of KidsArm (a sophisticated teleoperated surgical system designed to specifically to operate on small children and babies). The device is now being used to augment surgeons' skills to perform neurosurgeries that are traditionally considered difficult or impossible, thus leading to better patient outcomes.

Like Irmis[®], the Image Guided Autonomous Robot (IGAR) was designed to work in conjunction with an MRI that is highly sensitive to early detection of suspicious breast lesions. It is being used in clinical trials right now to provide increased access, precision, and dexterity in placing the biopsy and ablation tools within 1mm of the lesion.

Wound Treatment with Cold Plasma: Technology developed to study dusty plasmas—a mixture of small particles in the charged gases of a plasma—has led to new insights into this unusual type of matter. Understanding the modes and dynamics of this mixed form of matter helps researchers on the ground understand the antibacterial properties of cold plasmas and how to apply those fundamental discoveries to new technologies. Knowledge gained from this ESA-sponsored ISS research has been applied in Europe to develop a medical device called terraplasma GmbH for disinfecting wounds, neutralizing drug-resistant bacteria, and promoting improved wound healing time.

Earth Observation and Space Science

Measuring Cyclones from ISS: Atmospheric scientists at Visidyne, Inc. captured time-lapse images of tropical cyclones using automated and handheld cameras aimed through one of the portals on Station. This imagery is used to measure the heights and temperature of the cloud tops just outside the clear eye at the center of the storm, where the highest winds and most torrential rainfall are located. Combining these measurements with other data allows scientists to retrieve the storm's central sea-level air pressure, which leads to more accurate prediction of the intensities (peak wind speeds) and paths of the storms before they hit land. It also provides an increased understanding of the eyewall replacement cycle.

Monitoring the Earth's Atmosphere: The Stratospheric Aerosol and Gas Experiment III (SAGE III) was launched to ISS in February 2017, and stands ready to follow in the footsteps of its predecessor facilities to capture atmospheric data that could contribute to long-term monitoring of ozone vertical profiles that inform international assessment activities of ozone depletion and climate change. The SAGE III instrument's primary objective is to monitor the vertical distribution of aerosols, ozone, and other trace gases in the Earth's stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the stratosphere and upper troposphere. In the event of natural disasters, such as volcanic eruptions, these ISS-based observations and measurements assist decision makers and first responders in addressing public health and aviation impacts.

Ocean Vector Winds: ISS-RapidScat, which operated from September 2014 until August 2016, was a scatterometer that measured wind speeds and direction over the ocean. These measurements were used in near-real time to improve weather forecast models, including storm events, used by the United States Navy, the National Oceanic and Atmospheric Administration, and by European and Indian scientists.

Images from Space Station Aid in Disaster Response: The Station offers a unique vantage for observing the Earth's ecosystems with both hands-on and automated equipment. Station crews can observe and collect camera images of unfolding events as they occur. They may also provide input to ground controllers for the programmed observations of the Station's automated Earth-sensing systems. This flexibility is an advantage over sensors on unmanned spacecraft, especially when unexpected natural events such as volcanic eruptions and earthquakes occur. The full suite of ISS instrument sensors is informed of activations under the International Disaster Charter (IDC) so that images and data related to floods, droughts, and other events can be distributed to U.S. and international agencies responding to the crises. During FY 2017, ISS instruments received 45 IDC activations.

Exploring the Universe: Humanity's understanding of the universe is being expanded through experiments flown to the ISS. The Alpha Magnetic Spectrometer (AMS), launched in 2011, is a multinational partnership led by the U.S. Department of Energy that is unlocking the secrets of dark matter. The Cosmic-Ray Energetics and Mass for the International Space Station (ISS-CREAM) was launched in 2017 to learn how cosmic rays are accelerated to the tremendous energies—far beyond what is produced in particle accelerators here on Earth—at which they pass through the universe. The Neutron star Interior Composition Explorer (NICER) studies the extraordinary physics of neutron stars, and may pave the way for a future GPS-like system for spacecraft navigation anywhere in the solar system. Today's basic astro-

physics research aboard is advancing NASA's strategic objectives in astrophysics and expanding humanity's understanding of the universe.

Innovative Technologies

Medical Device Technology use Space-Validated Fluid Models: The Capillary Flow Experiments examined capillary flows in space and led to an understanding of how to make liquids behave and how to influence where the liquid goes using passive forces of wetting and surface tension. They also led to the first space-validated models describing fluid behavior in space. These models and measurements are now being applied to the design of a technology called the Human Emulation System. This "organ on chip" can be used for predicting human response to diseases, medicines, chemicals, and foods.

Improving Semiconductors with Nanofibers: Research on the ISS led to the development of a two-dimensional nanofiber layer that can assemble by itself into a very tight, repeating pattern. This material layer was used as a template that can be traced like a blueprint to mark the processing surface of a semiconductor. This novel process can be useful in developing new motherboards and computers and in creating chemical catalysts for industrial processes. Nano-patterned surfaces can also be used to detect individual molecules, which may improve research on new drugs to treat human diseases.

Technology Applications for Clean Water: Water recycling, oxygen generation, and carbon dioxide removal are critical technologies for reducing the logistics re-supply requirements for human spaceflight. This ISS demonstration project is applying lessons learned from operational experiences to next-generation technologies. The resin used in the ISS water processor assembly has been developed as a commercial water filtration solution for use in disaster and humanitarian relief zones in portable water filtration plants. The system has successfully provided clean water after natural disasters and in community development projects around the world.

Space Commerce

A Gateway to Space: A series of CubeSats—small satellites, each about the size of a loaf of bread—are delivered to ISS and jettisoned into orbit using the NanoRacks CubeSat Deployer (NRCSD) and JAXA's Japanese Exposure Module-Small Satellite Orbiter Deployer (J-SSOD), from the Japanese Kibo module. These deployers provide a gateway to the extreme environment of space for Earth- and deep space observation. They are self-contained deployment systems that consist of rectangular launchers that deploy the small satellites to place them into orbit, and they have opened up new possibilities for U.S. Government organizations, commercial companies, and universities across the globe as a gateway to space. The satellites conduct a variety of studies, such as Earth observation, including studying weather patterns or monitoring the gaseous molecules in the atmosphere. More than 180 CubeSats have been deployed from the Station.

Growth of the U.S. National Laboratory

The CASIS mission is to facilitate use of the ISS National Laboratory by academic researchers, other Government organizations, startups, small businesses, and major commercial companies. More than half of these projects launched in FY 2017 involved commercial entities that funded their research and development efforts to the ISS National Lab. They include several Fortune 500 companies including Merck, Procter and Gamble, Eli Lilly, Hewlett Packard, and Boeing. In August 2017, Target and CASIS launched the ISS Cotton Sustainability Challenge to identify innovative ideas for the sustainability of cotton. In addition to these commercial entities, CASIS is sponsoring a protein crystal growth investigation led by the Michael J. Fox Foundation. This study optimizes crystallization of human protein kinase Leucine-rich repeat kinase 2 (LRRK2), which is a key signaling molecule in neurons and is tightly associated with the development of Parkinson's disease.

In addition, ISS National Lab projects funded by other U.S. Government agencies (*i.e.*, non-NASA) continued to increase to include flight projects funded by the NIH's NCATS as a part of its Tissue Chip for Drug Screening program; the NSF combustion and thermal transport research, and the Department of Defense (DoD) technology development and space test programs.

SMALL BUSINESS INNOVATION RESEARCH (SBIR)

NASA's SBIR program leverages the Nation's innovative small business community to support early-stage research and development in support of NASA's mission in science, technology, human exploration, and aeronautics. This program provides the small business sector with an opportunity to compete for funding to develop

technology for NASA, and to commercialize that technology to spur economic growth.

NASA hopes to incorporate SBIR-developed technologies into current and future systems to contribute to the expansion of humanity across the solar system while providing continued cost-effective ISS operations and utilization for its customers, with a high standard of safety, reliability, and affordability. Technology developed under the SBIR program is transforming NASA's understanding of the complex issues regarding space exploration and revolutionizing technology that will deliver humans into the next stage of planetary exploration.

Successful SBIR programs on ISS include:

Techshot Bone Densitometer (Phase 3/\$3,600,000): Techshot, Inc. (Greenville, IN) developed the first X-ray machine onboard the ISS. The bone densitometer is being used to study the bone density of rodents in microgravity. Bone loss is one of the primary challenges of long-duration spaceflight. The bone densitometer flew to the ISS in September 2014 onboard SpaceX CRS-4 and has been used in multiple rodent investigations so far, with plans for further use in upcoming investigations.

Techshot Analytical Containment Transfer Tool (ACT2) (Phase 2e/\$150,000): In 2010, the Agency's ability to analyze the DNA of biospecimens in space was more limited. Samples were collected, frozen, and analyzed post flight. Since return capsules didn't yet exist, the samples had to be sent back to Earth with returning crew. In addition, separate tools were needed for collection and analysis, making the transfer of samples from the Space Shuttle to the laboratory a delicate process. The resulting ACT2 is a device that both contains and transfers samples in a safe manner from unique experiment-specific, spaceflight hardware to on-orbit analytical tools for real-time analysis. There is no need to send the sample back down to Earth, which was the previous protocol. NASA understood the ability to do this was a crucial step for performing in-flight analysis. It's not only safer to use than the previous combination of tools, but because it is disposable, it is cost effective as well. The ACT2 flew to the ISS in February 2016 with SpaceX CRS-8. Recently, Techshot received a \$9.5 million Indefinite Delivery Indefinite Quantity (IDIQ) contract with NASA. Spanning five years, the agreement essentially is a menu of services and hardware, such as the ACT2, that the Agency can buy at pre-negotiated rates.

Aurora Flight Sciences ISS Universal Battery Charging Station (Phase 2e/\$83,500; Phase 3/\$167,000): Aurora Flight Sciences (Cambridge, MA) has developed a Universal Battery Charger (UBC) for use on the ISS capable of interfacing with the most commonly used batteries on board. This technology reduces the number of chargers and single-use batteries required on the ISS, reducing the cost of ISS operations and resupply logistics. The UBC flew to the ISS in February 2016 onboard SpaceX CRS-8.

Orbital Technologies Corporation Zero-G Mass Measurement Device (ZGMMD) (Phase 2X/\$300,000): Orbital Technologies Corporation (Madison, WI) developed the Zero-Gravity Mass Measurement Device to measure the mass of biological specimens (e.g., rodents and plants) in a microgravity environment. Knowing the mass of the biological specimen is integral to experimental manipulations (including anesthesia and drug doses). Once the hardware is flight-ready, it will be scheduled for launch to the ISS.

Terminal Velocity Aerospace Low Cost Small Re-Entry Devices to Enhance Space Commerce and ISS Utilization (Phase 3/\$300,000): Terminal Velocity Aerospace (Atlanta, GA) developed Re-Entry Devices (REDs) as a low-cost solution to returning small payloads from the ISS. These payloads are about the size of four CubeSats, and are deployed from the ISS to return small payloads. Smaller, alternative versions have also been developed that can record critical onboard engineering data from spacecraft reentering the atmosphere. The first group of REDs flew to the ISS in April 2017 onboard the Orbital ATK CRS-7.

4.6: TECHNICAL EVALUATION OF EXTENDING ISS THROUGH THE 2020s

There has been much discussion about the physical life of the ISS in recent years. A technical feasibility end date of 2028 has been informally discussed for several years; this was based on the expected 30-year structural life of the first on-orbit elements of the ISS that were launched in 1998—the FGB and the U.S. Node 1. However, many elements of the ISS could have a life expectancy well beyond the 2020s. The following technical assessment is a bottoms-up structural assessment of the ISS elements through 2028. Technical assessments beyond 2028 have not been performed. Also highlighted below are the critical system elements that would need to be replaced and/or augmented to continue with nominal ISS operations toward the end of the 2020s.

Structural Life Assessment

NASA is performing a structural life assessment on the major U.S. structural elements, including truss segments, solar arrays, radiators, pressurized modules (including the U.S.-owned, Russian-built Functional Cargo Block [FCB]), docking adapters, common berthing mechanisms, and external stowage platforms. The analysis is based upon the design life of the elements and the actual performance of the on-orbit vehicle as measured by *in situ* measurements on structural items, cycle loading of the vehicle from reboost operations, and loading from docking vehicles. All of the elements have been structurally cleared through 2024.

As can be seen in Table 1, all of the U.S. elements that have been on orbit for an extended time have also been cleared to 2028. The items in Table 2 have been cleared to 2020 based on their launch date and 15-year design life. These items have yet to be officially cleared to 2028, but given that these elements have been on orbit for a shorter time than the items in Table 1, it is anticipated that the structural margin of the ISS would be fully adequate to support ISS operations to 2028. The analysis to date indicates that there would be sufficient remaining margin to operate even beyond 2028. This analysis is scheduled to be completed by 2019.

Hardware	Design End of Life	Life Extension End of Life
Functional Cargo Block (FCB)	Nov 2013	Dec 2028
Node-1	Dec 2013	Dec 2028
Pressurized Mating Adapter 1/2 (PMA-1/2)	Dec 2013	Dec 2028
Pressurized Mating Adapter 3 (PMA-3)	Oct 2015	Dec 2028
Hatches	various	Dec 2028
Common Berthing Mechanisms (CBMs)	various	Dec 2028
Z1 Truss	Oct 2015	Dec 2028
Z1/P6 Rocketdyne Truss Attachment System (RTAS)	Oct 2015	Dec 2028
P6 Integrated Electronics Assembly (IEA)	Dec 2015	Dec 2028
P6 IEA Fin Plate (FP)	Dec 2015	Dec 2028
P6 Long Spacer (LS)	Dec 2015	Dec 2028
P6 Photovoltaic Radiator (PVR)	Dec 2015	Dec 2028
P6 Solar Array Wing (SAW)	Dec 2015	Dec 2028
P6 Beta Gimbal Assembly (BGA)	Dec 2015	Dec 2028

U.S. Lab	Feb 2016	Dec 2028
U.S. Airlock	Jul 2016	Dec 2028
Module-to-Truss Structure (MTS) Struts	Apr 2017	Dec 2028
S0 Truss	Apr 2017	Dec 2028
Mobile Transporter (MT)	Apr 2017	Dec 2028
External Stowage Platform-1 (ESP-1)	Mar 2016	Dec 2028
External Stowage Platform-2 (ESP-2)	Jul 2020	Dec 2028
S1 Truss	Oct 2017	Dec 2028
S1 Thermal Radiator Rotary Joint (TRRJ)	Oct 2017	Dec 2028
S1 Heat Rejection System (HRS)	Oct 2017	Dec 2028
P1 Truss	Nov 2017	Dec 2028
P1 Thermal Radiator Rotary Joint (TRRJ)	Nov 2017	Dec 2028
P1 Heat Rejection System (HRS)	Nov 2017	Dec 2028
P1/S0/S1 Segment-to-Segment Attach System 0/1 (SSAS)	various	Dec 2028
P1/P3 and S1/S3 SSAS	various	Dec 2028

Table 1. Completed Structural Assessments
(Green = cleared through 2028)

Forward Work - Hardware	Design End of Life
P3, P4 Truss Segment	Sep 2021
P5 Truss Segment	Dec 2021
S3, S4 Truss Segment	Jun 2022
S5 Truss Segment	Aug 2022
External Stowage Platform-3 (ESP-3)	Aug 2022
S6 Truss Segment	Mar 2024
EXPRESS Logistics Carrier-1 (ELC-1)	Nov 2024
EXPRESS Logistics Carrier-2 (ELC-2)	Nov 2024
EXPRESS Logistics Carrier-4 (ELC-4)	Feb 2026
EXPRESS Logistics Carrier-3 (ELC-3)	May 2026

Table 2. Structural Assessments to be Completed by 2019

Non-Replaceable and Critical Hardware

In addition to assessing the structural integrity of the vehicle, each of the key subsystems has been systematically analyzed to ensure that its functionality and safe operations can be sustained over the projected life extension. These analyses focused primarily on critical structural hardware (*e.g.*, pressure vessels), the failure of which would be catastrophic; critical operating hardware that is not replaceable and has no identified operational workaround; on-orbit replacement units (ORUs) or components for which a technical time or cycle issue would drive limited life or operational reductions; and operating hardware with functionality that is necessary for crew habitation or provides the capability to perform the science mission. Hardware items that matched these criteria were examined on a case-by-case basis. Additional work would be required for life extension to 2028 and beyond.

Critical functional capabilities that have been assessed and cleared include: electrical power; thermal control; environmental control and life support; propulsion; guidance, navigation and control; communications and tracking; command and data handling; extravehicular activity; and crew health care.

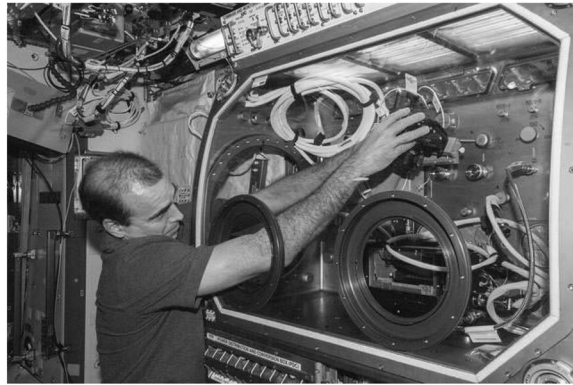
Additionally, system upgrades necessary to operate the ISS beyond 2020 have been implemented or are already under development. Such systems include lithium ion batteries (part of the electrical power system), power generation augmentation, oxygen and nitrogen composite overwrap resupply tanks, upgraded communication systems, docking systems, and rendezvous radio. The ISS is being upgraded with these systems over the next few years, which would support ISS operations beyond 2024.

System upgrades on the current Extravehicular Mobility Units (EMUs) are also being implemented. This includes new batteries, inclusion of a high rate data recorder, point-of-use filters to further purify cooling water, and a new carbon dioxide sensor. All upgrades have applicability toward the development of a new exploration suit. New suit technology development for water cooling is presently underway, with deployment to the ISS in 2018. In addition, funding is in place to develop and deploy this new suit for extensive checkout on the ISS. Production of a fleet of new exploration suits is still under consideration, and will be a future trade versus extending the current EMUs past 2024.

Like the core systems, critical scientific capabilities have also been reviewed for supportability and continued safe operations. Permanent payload facilities supporting utilization on the ISS that have been cleared to 2020 or beyond include:

- EXPedite the PROcessing of Experiments to the Space Station (EXPRESS) racks (a standardized payload rack system for transporting, storing, and supporting experiments on the ISS);
- Human Research Facility (HRF);
- Window Observational Research Facility (WORF);
- Combustion Integrated Rack (CIR);
- Fluids Integrated Rack (FIR);
- Microgravity Science Glovebox (MSG) (shown in the image below);
- Materials Science Research Rack (MSRR).

The ISS Program is currently evaluating the performance of these facilities through at least 2028. Assessments to date of the few cycle-limited components indicate sufficient margin for operation well beyond 2024 based on current predictions of facility use beyond this timeframe.



NASA astronaut Rick Mastracchio sets up the Microgravity Science Glovebox (MSG) for a combustion experiment in February 2014.

Functional Availability and Sparing Assessments

A comprehensive logistics analysis is performed each year to ensure that the proper quantities of spares (ORUs) are available. NASA assesses the expected functional availability of its systems to determine the type and quantity of spares that will be needed over time to sustain system operations. This analysis takes into account many factors, including age of the components and expected on-orbit performance based on mathematical analyses and actual hardware performance history. Analysis shows the sparing requirements would remain relatively flat as the ISS is operated beyond the current expected operational lifetime to at least 2028. This holds true for consumables as well. Consumables are those items required to sustain the crew and normal operation of the systems, including food, clothing, water, medicines, and waste and hygiene items. Over the years of ISS operation, the ISS Program has determined the minimum amount of consumables required to support operations. Consumables requirements are well understood and expected to remain stable. The only expected increase in consumables is associated with the fourth USOS crewmember, enabled by new commercial crew transportation capabilities via the Commercial Crew Program.

The only projected additional requirements for the ISS beyond 2024 in its current form, are the varying types and amount of new hardware necessary to conduct new research and technology development on the ISS. Much of the research growth is expected to come from private industry and other Government agencies.

Consumables, spares, system upgrades, and new utilization hardware are delivered to the ISS via an international cargo vehicle fleet, comprised of the Russian Progress, Japanese HII Transfer Vehicle (HTV), SpaceX Dragon, and Orbital ATK Cygnus. All of these uncrewed cargo vehicles deliver pressurized cargo. External ORUs are primarily delivered via the HTV or the Dragon. The primary means of returning hardware, research samples, and other items to the ground is the Dragon vehicle, although smaller items can also be returned with the crew on the Soyuz vehicle (Sierra Nevada Corporation's Dream Chaser is expected to come online in 2019 and will provide both pressurized and unpressurized cargo delivery, as well as pressurized cargo return). The other vehicles, destroyed on re-entry after departing the ISS, are used to dispose of trash and no-longer-needed equipment.

International Partner Hardware

All the ISS partners have responsibility for assessing the capability of their elements and systems with respect to an ISS lifetime extension. The Russian elements have been cleared through 2020 and are in the process of being cleared to 2028, with no known issues. CSA has identified no major issues with the robotic elements to 2028, including the ISS robotic arm, Mobile Remote Servicer Base System, and Special Purpose Dexterous Manipulator. The JAXA elements are cleared to 2020

and analyses for extension to 2028 are planned. The ESA assessments to 2028 are complete and cleared.

Safety Considerations

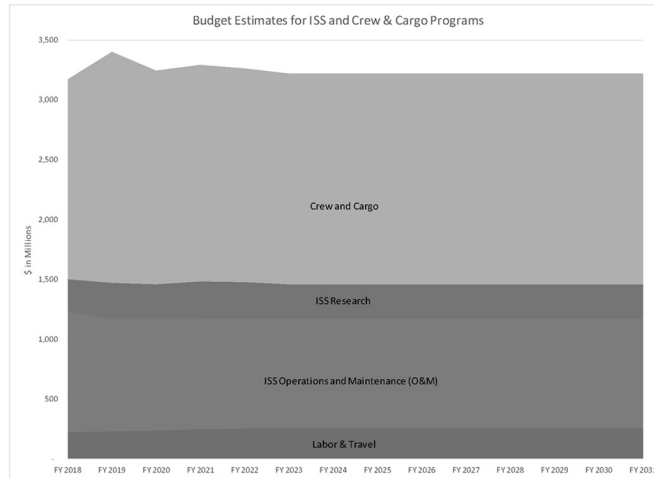
The safety and mission assurance community has been involved throughout all of these assessments. Work continues to review existing hazard reports and other ISS documentation for any safety issues relative to the ISS lifetime extension.

From a technical risk perspective, the same risks for the ISS that exist today will exist through at least 2024 and beyond. Micrometeoroid and orbital debris (MMOD) penetration of the pressure shell remains the largest risk to the ISS. The likelihood of penetration will increase as a function of the life of ISS on-orbit, although the likelihood of penetration in any six-month period is expected to remain stable. The USOS segment was designed with debris shields that protect the pressure shell from MMOD debris to about one centimeter in size. The Russian segment was not designed to the same shielding specifications, but has been modified over the years to enhance the MMOD protection capability. The final planned modification, which has already been implemented, is an additional external shield for the Progress logistics vehicle. Also, the ISS has an improved capability to maneuver to avoid objects that are large enough to be tracked, using the Predetermined Debris Avoidance Maneuver, which reduces the amount of notice necessary to perform a maneuver from over a day to down to just a few hours. The risks of operating in LEO are heavily outweighed by the benefits to the U.S. economy, human health and well-being, and the Nation’s strategic goals in leadership and exploration of deep space.

Station is demonstrably more capable of operating in LEO today than it was 15 years ago, and this experience has shown that NASA and its partners are able to conduct safe and effective operations in LEO onboard the ISS. While the risks inherent in operating in space cannot be eliminated, the technical environment is well understood through 2028.

4.7: COST ESTIMATES OF ISS EXTENSION

The ISS Program analyzes its program and budget requirements on an annual basis. The budget estimate for ISS life extension to 2024, 2028, and 2030 based on its current configuration, including the Crew and Cargo Program, are provided in the figure below.



(\$ in M)	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	FY 2030	FY 2031
Budget Estimates	3,174	3,398	3,246	3,294	3,259	3,222	3,222	3,222	3,222	3,222	3,222	3,222	3,222	3,222
ISS Systems O&M	1,009	938	932	927	921	916	916	916	916	916	916	916	916	916
ISS Research	267	303	294	308	300	283	283	283	283	283	283	283	283	283
Crew and Cargo	1,673	1,927	1,784	1,813	1,783	1,761	1,761	1,761	1,761	1,761	1,761	1,761	1,761	1,761
Labor and Travel	225	231	237	245	254	262	262	262	262	262	262	262	262	262

ISS Life Extension Budget Estimate (out years notional); Includes Crew & Cargo Program

Within the above budget details, ISS Systems Operations and Maintenance (O&M) supports vehicle operations in the extreme conditions of space with constant, around-the-clock support. ISS Research supports research on ISS across a diverse array of disciplines, from fundamental physics and biophysics to human physiology and biotechnology. ISS Research also supports CASIS, the non-profit organization that manages the ISS National Laboratory. Funding for research varies depending on the individual payloads and other work in development. Crew and Cargo supports transportation to and from the ISS, for both crew and cargo. Labor and travel supports civil servant labor and travel.

The cost estimates provided in this section assume that ISS will be de-orbited rather than turned over to a commercial entity due to the number of potential options for that scenario. Cost estimates for life extension through 2024 would be reflective of the budget above through FY 2025 with deorbit in January 2025. Cost estimates for life extension through 2028 would be reflective of the budget above through FY 2029 with deorbit in January 2029. Cost estimates for life extension through 2030 would be reflective of the budget above through FY 2031 with deorbit in January 2031. As NASA begins to shift responsibility for meeting its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness, it could offer the prospect of lowering the above projected cost to the Government.

The budget estimates are based on the following major assumptions:

- Reflects the FY 2018 President's Budget Request for FY 2018 and the FY 2019 President's Budget Request for FY 2019 through FY 2023.
- International Partner commitments continue through the life of the Program.
- Inflation is estimated at the current contract rates or rates experienced within that service line. NASA is expecting to achieve cost efficiencies in order to absorb inflationary impacts within a flat budget.
- Funds Soyuz crew rotation and rescue services through spring of 2019 and landing in fall of 2019. Assumes six-person crew operations until commercial crew transportation begins.
- Legislative relief is obtained from the limitations in the Iran, North Korea and Syria Nonproliferation Act (INKSNA).
- U.S. Visiting Vehicles include CRS for cargo transportation and commercial crew operational services for crew rotation through the life of ISS.
 - The budget covers an average of four to five CRS missions and two commercial crew missions per year.
 - Once commercial crew transportation begins, the crew complement will increase from six to seven persons; USOS crew size will permanently increase from three to four.
- Consumables content is based on performance analysis and/or inventory assessment.
- Corrective maintenance cost estimate is based on the current hardware reliability performance.
- There will be no more than one major USOS software update per year through the life of ISS.
- Six planned USOS EVAs are supported per year.
- ISS deorbit and closeout costs through FY 2024, 2028, or 2030 can be absorbed within a flat budget profile. As crew and cargo flights reduce near ISS end of life, those funds will be re-directed to purchase de-orbit vehicles. Likewise, as spares purchases decrease near ISS end of life, those funds will be re-directed towards closeout activities.
- Transportation and integration costs for the National Lab research will continue to be provided by NASA.
- Additional funds required to support the development of commercial modules in LEO or on ISS are not included in the above budget. Commercial partner development of capabilities that the private sector and NASA can use will be funded by the Commercial LEO Development budget line.

4.8: COMMUNITY INPUT

On August 9, 2017, NASA held a workshop in Washington, D.C., to engage ISS stakeholders in gathering information that may be used in the development of NASA's future planning activities. Specifically, the workshop targeted the commercial space sector, researchers, technology developers, transportation and habitation

providers, other Government agencies, and other interested parties, providing a forum for dialogue with NASA on topics relevant to Station future planning. Approximately 130 people attended the workshop. Four breakout sessions addressed the LEO market, the value proposition of human spaceflight, public-private partnerships, and access to space. A complete summary of the workshop, including presentations, can be found here: <https://www.nasa.gov/content/international-space-station-stakeholder-workshop>

There were several main themes from the workshop:

- Attendees stated that a formal acknowledgment of a LEO human-spaceflight-enabled commercial policy would be helpful for building business cases. Specifically, this would lend credibility to the idea that a need for LEO access and capabilities is ongoing, which would aid in long-term planning.
- Attendees stated that it is important that the Government maintain its demand for human-spaceflight-enabled LEO capabilities, and that it quantify its needs where possible. The National Laboratory part of the ISS Program is working well, and is facilitating access to the microgravity environment and ISS platform in a way that is conducive to business and development.
- The attendees expressed a strong desire for a pricing policy from NASA for services in LEO. While things like launch, crew time, power, and data transmission are currently free for users under the National Lab, this may not always be the case as demand for these services increases and the availability becomes more constrained. Ideas for study suggested by participants included examining the pricing policy of other Government agencies that regulate constrained markets, such as the Federal Communications Commission (FCC) for spectrum licensing, and the Forestry Service for logging rights. The idea of maintaining free access for users under the National Lab while also providing a for-pay “priority access” capability was also raised by participants and discussed as a group.
- There was a broad desire to maintain U.S. leadership in LEO. Attendees voiced little confidence in the ability of foreign platforms to provide the kind of capability, reliability, and security needed to maintain long-term business planning.
- Finally, attendees said that any transition away from ISS needs to be gradual and well-planned.

5.0: CONCLUSION

The ISS is in its intensive research and technology demonstration phase and is enabling a maturing commercial market. The maturity and stability of the ISS Partnership allows the United States to demonstrate global leadership in human spaceflight and technology development and is already providing the foundation for continuing human spaceflight beyond LEO. Closer to home, NASA’s ISS National Laboratory partners can use the unique capabilities aboard Station to enable investigations that may give them the edge in developing valuable, high technology products and services for the global market. Furthermore, the demand for access to the ISS enables the establishment of robust U.S. commercial crew and cargo capabilities. Both of these aspects of the ISS National Laboratory will help establish the U.S. market for research in LEO beyond the current NASA requirements.

NASA is actively developing transition strategies for the concurrent-and post-ISS LEO era and is engaged with the private sector to foster both private demand and supply for LEO services. It is NASA’s intention to continue to foster the development of private industry capabilities and private demand with a goal to end direct Federal support for the ISS by 2025 when, NASA intends to be one of many customers, including both private and other Government agencies, for LEO platforms.

With this approach, NASA believes that the Nation’s interest in human spaceflight and LEO are protected and enhanced while relying on private industry to provide the services and capabilities to meet NASA’s needs. This approach also offers the prospect of lower cost to the Government by leveraging private industry capacity and innovation through a commercial marketplace where NASA is one of many customers and provides the basis for determining the long-term future of the ISS Platform along with the ISS International Partners.

NASA looks forward to working with Congressional stakeholders along with researchers, private industry and our ISS International Partners to ensure that the U.S. maintains our human spaceflight leadership in LEO while expanding human presence into the solar system and returning benefits to U.S. taxpayers.

APPENDIX—EXCERPT FROM NASA TRANSITION AUTHORIZATION ACT OF 2017
(P.L. 115–10)

SEC. 303. ISS Transition Plan

(c) REPORTS.—Section 50111 of title 51, United States Code, is amended by adding at the end the following:

(1) IN GENERAL.—The Administrator, in coordination with the ISS management entity (as defined in section 2 of the National Aeronautics and Space Administration Transition Authorization Act of 2017), ISS partners, the scientific user community, and the commercial space sector, shall develop a plan to transition in a step-wise approach from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a low-Earth orbit non-governmental human space flight enterprise.

(2) REPORTS.—Not later than December 1, 2017, and biennially thereafter until 2023, the Administrator shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a report that includes—

(A) a description of the progress in achieving the Administration’s deep space human exploration objectives on ISS and prospects for accomplishing future mission requirements, space exploration objectives, and other research objectives on future commercially supplied low-Earth orbit platforms or migration of those objectives to cis-lunar space;

(B) the steps NASA is taking and will take, including demonstrations that could be conducted on the ISS, to stimulate and facilitate commercial demand and supply of products and services in low-Earth orbit;

(C) an identification of barriers preventing the commercialization of low-Earth orbit, including issues relating to policy, regulations, commercial intellectual property, data, and confidentiality, that could inhibit the use of the ISS as a commercial incubator;

(D) the criteria for defining the ISS as a research success;

(E) the criteria used to determine whether the ISS is meeting the objective under section 301(b)(2) of the National Aeronautics and Space Administration Transition Authorization Act of 2017; [Reference: 301(b)(2): “to pursue a research program that advances knowledge and provides other benefits to the Nation”]

(F) an assessment of whether the criteria under sub-paragraphs (D) and (E) are consistent with the research areas defined in, and recommendations and schedules under, the current National Academies of Sciences, Engineering, and Medicine Decadal Survey on Biological and Physical Sciences in Space;

(G) any necessary contributions that ISS extension would make to enabling execution of the human exploration roadmap under section 432 of the National Aeronautics and Space Administration Transition Authorization Act of 2017;

(H) the cost estimates for operating the ISS to achieve the criteria required under subparagraphs (D) and (E) and the contributions identified under subparagraph (G);

(I) the cost estimates for extending operations of the ISS to 2024, 2028, and 2030;

(J) an evaluation of the feasible and preferred service life of the ISS beyond the period described in section 503 of the National Aeronautics and Space Administration Authorization Act of 2010 (42 U.S.C. 18353), through at least 2028, as a unique scientific, commercial, and space exploration-related facility, including—

(i) a general discussion of international partner capabilities and prospects for extending the partner-ship;

(ii) the cost associated with extending the service life;

(iii) an assessment on the technical limiting factors of the service life of the ISS, including a list of critical components and their expected service life and availability; and

(iv) such other information as may be necessary to fully describe the justification for and feasibility of extending the service life of the ISS,

including the potential scientific or technological benefits to the Federal Government, public, or to academic or commercial entities;

(K) an identification of the necessary actions and an estimate of the costs to deorbit the ISS once it has reached the end of its service life;

(L) the impact on deep space exploration capabilities, including a crewed mission to Mars in the 2030s, if the preferred service life of the ISS is extended beyond 2024 and NASA maintains a flat budget profile; and

(M) an evaluation of the functions, roles, and responsibilities for management and operation of the ISS and a determination of—

(i) those functions, roles, and responsibilities the Federal Government should retain during the lifecycle of the ISS;

(ii) those functions, roles, and responsibilities that could be transferred to the commercial space sector;

(iii) the metrics that would indicate the commercial space sector's readiness and ability to assume the functions, roles, and responsibilities described in clause (ii); and

(iv) any necessary changes to any agreements or other documents and the law to enable the activities described in subparagraphs (A) and (B).

