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 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 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." 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 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 crew-tended 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 capabilities 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 programmatics 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:

<u>Enabling a LEO Commercial Market</u>

<u>Allowing private industry use of ISS resources and crew and cargo transportation for commercial for-profit activities</u> – 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 Acadamies 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 environment. 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.

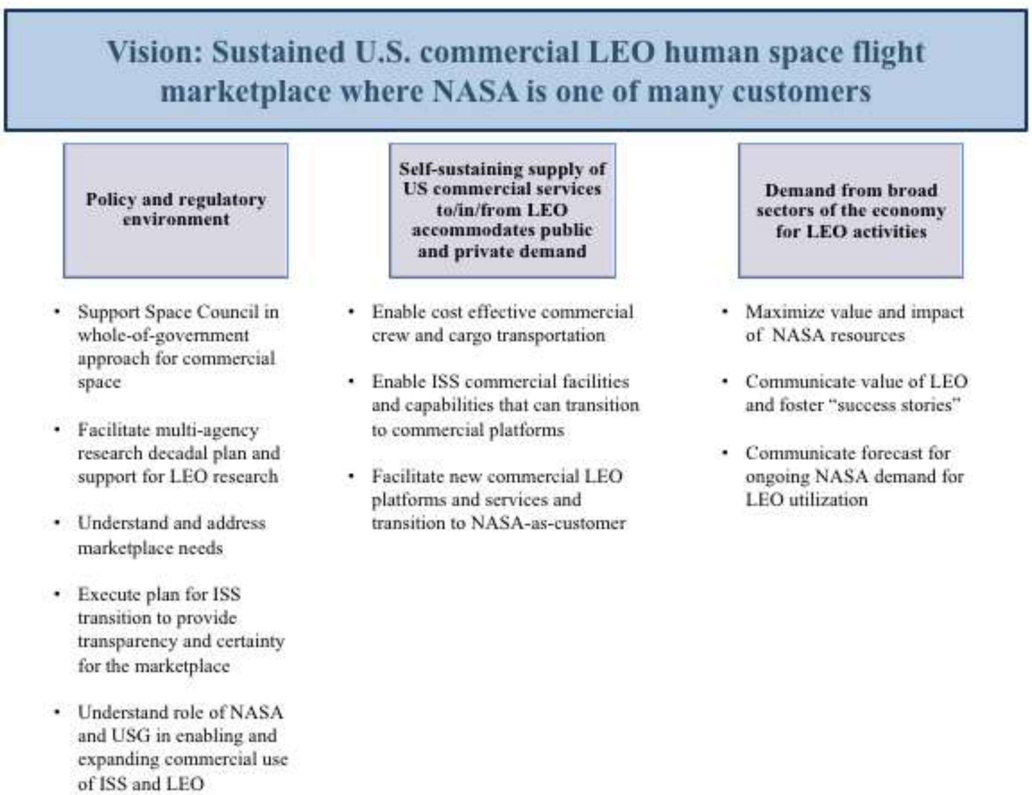
Conclusion

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 biofabrication;
- 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.

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

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

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 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.

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.

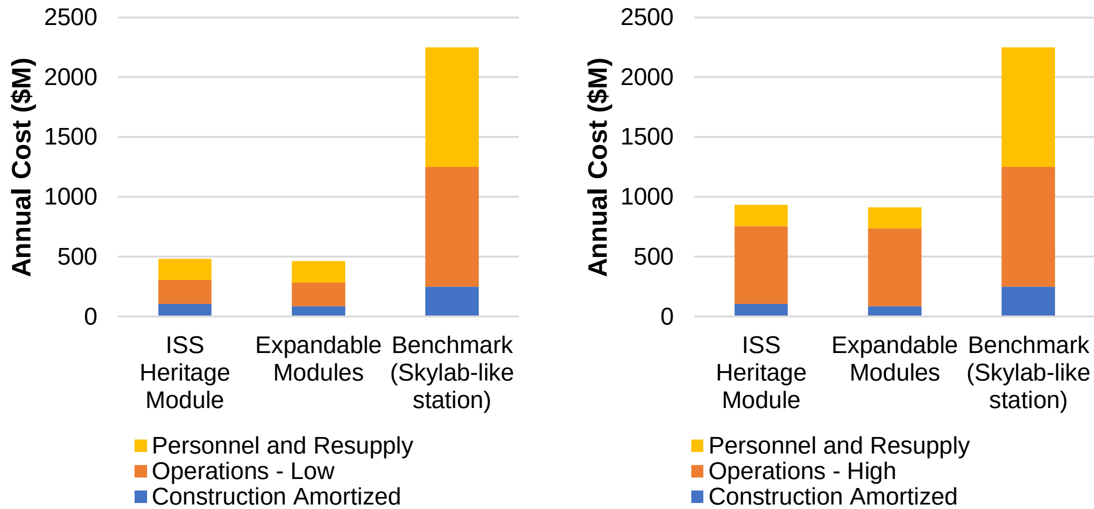
The "low" estimate for total annualized revenues from activities conducted on a space station is about $460 million, and the "high" estimate is roughly $1.2 billion. Manufacturing in space is the largest contributor to overall revenues, accounting for nearly 35 percent of the "high" estimate and more 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.

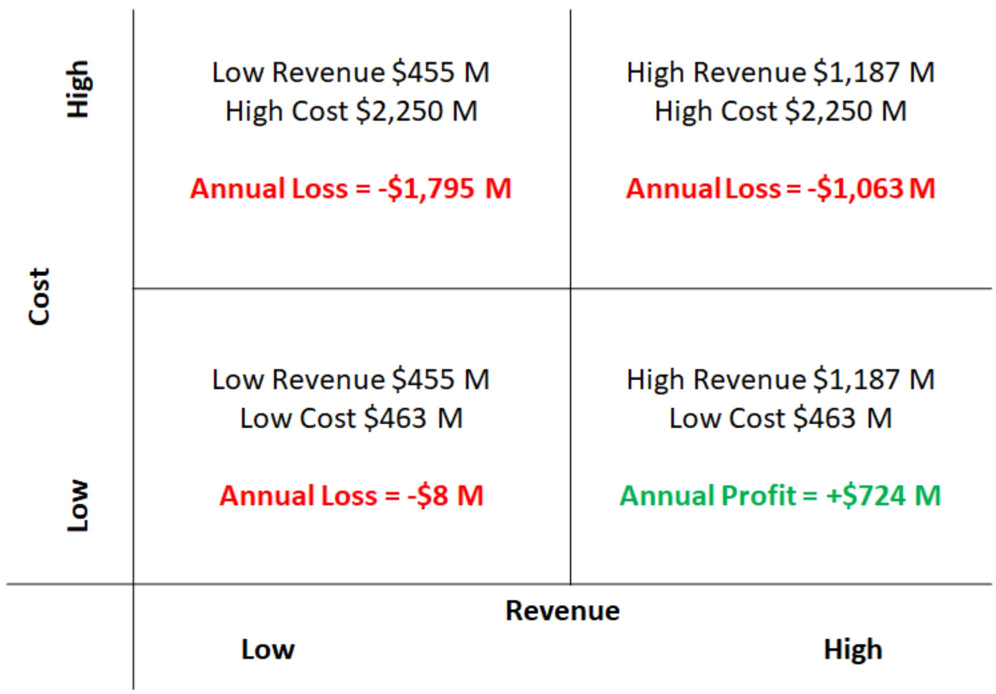
Private Space Station Potential Costs and Net Profits

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.*



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 investors. 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:

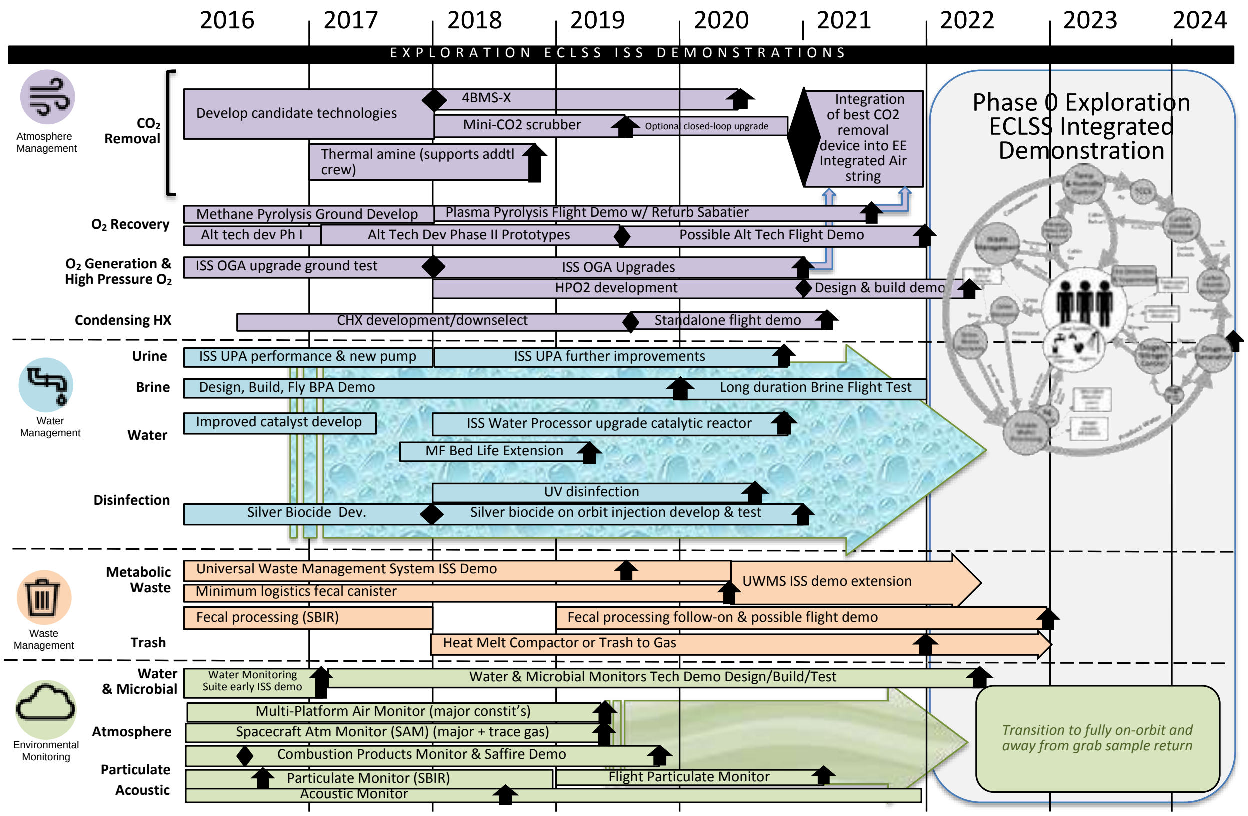
Environmental Control and Life Support Systems (ECLSS) and Environmental Monitoring
Leveraging the ISS, NASA is focused on demonstrating advanced capabilities for robust and reliable ECLSS, which must operate for up to 1,100 days with minimal spares and consumables. Water and oxygen for human exploration 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.

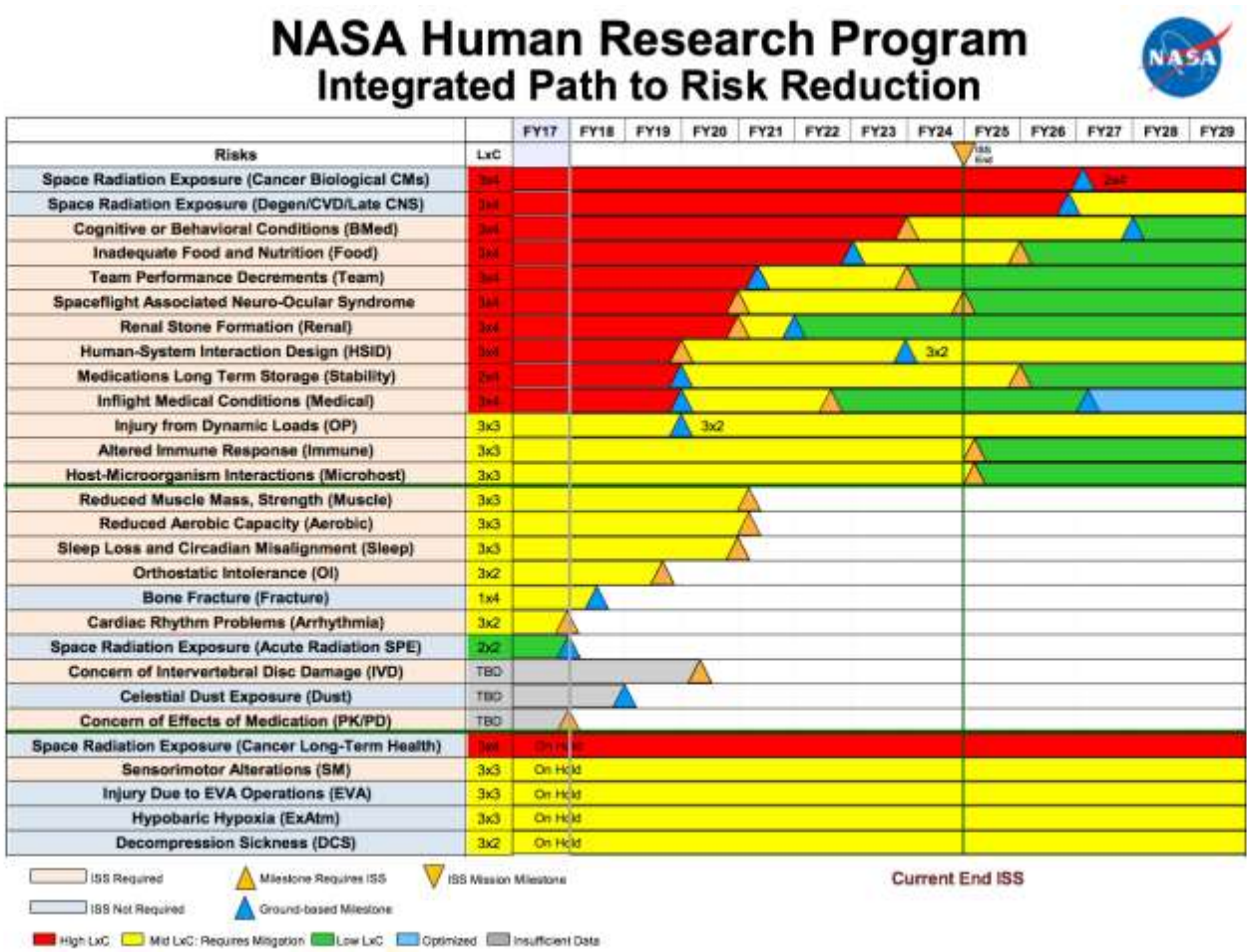
Early detection is key to protecting the crew and vehicle. The ISS uses smoke detectors to spot the presence of any potential fire-initiated problems. Advanced smoke detectors – about the size of a small tissue box – are under development for NASA's Orion spacecraft and eventual deep space habitats. 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 during 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 astrophysics 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, Proctor 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 [FGB]), 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 (FGB)	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

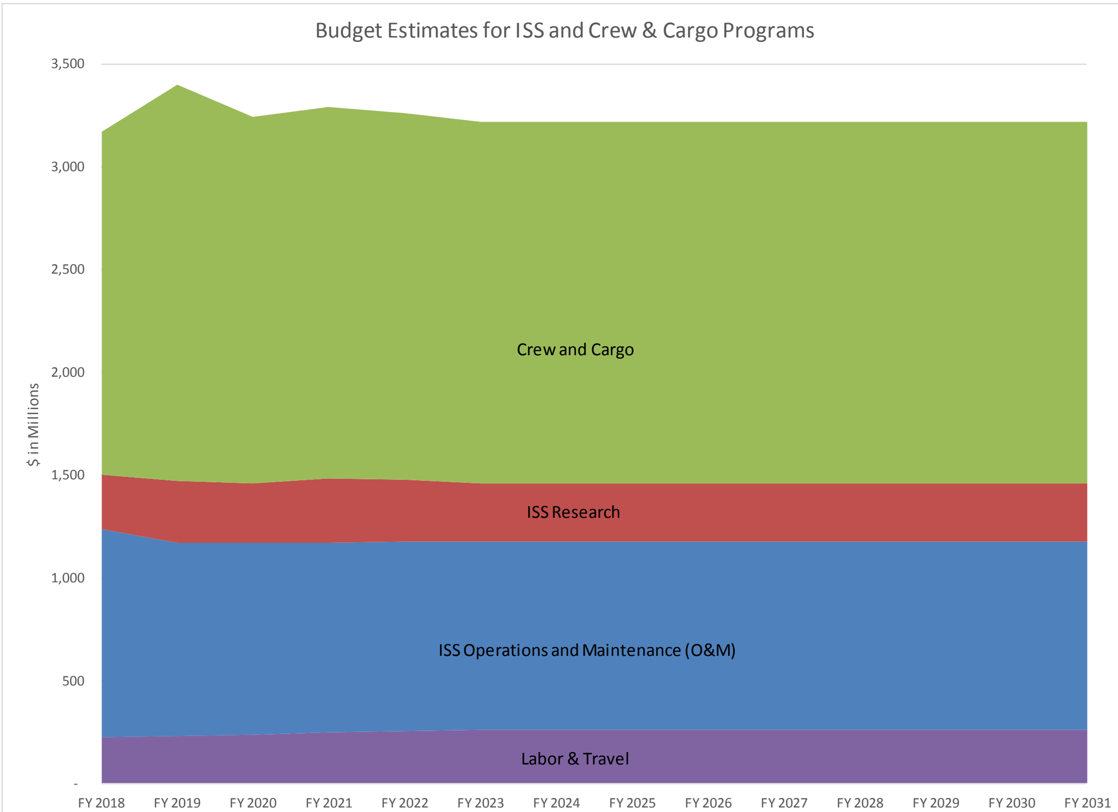
The safety and mission assurance community has been involved throughout all of these assessments. Work continues to review existing hazard reports and other ISS documentation for any safety issues relative to the ISS lifetime extension.

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).