ISS
U.S. NATIONAL LABORATORY

# International Space Station U.S. National Laboratory

# Annual Report for Fiscal Year 2019

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### *About the International Space Station (ISS) U.S. National Laboratory*

In 2005, Congress designated the U.S. portion of the ISS as the nation's newest national laboratory to optimize its use for improving quality of life on Earth, promoting collaboration among diverse users, and advancing science, technology, engineering, and mathematics (STEM) education. This unique laboratory environment is available for use by U.S. government agencies, academic institutions, and the private sector. The ISS National Lab manages access to the permanent microgravity research environment, a powerful vantage point in low Earth orbit, and the extreme and varied conditions of space.

*Our Mission* is to foster scientific discovery and technological innovation in space, expand U.S. leadership in commercial space, and inspire the next generation.

*The ISS National Lab is managed by the Center for the Advancement of Science in Space, under agreement with NASA.*

# Executive Summary

## *From Ken Shields, Chief Operating Officer of the International Space Station U.S. National Laboratory*

It is my honor to share with you the International Space Station (ISS) U.S. National Laboratory Annual Report for Fiscal Year 2019 (FY19; October 1, 2018 – September 30, 2019). Multiple ISS National Lab activities this year achieved all-time highs: We broke records for crew-time utilization hours, payloads delivered, new projects selected, and new-to-space customers added to the research and development (R&D) portfolio. Educational initiatives, social media engagements, and user sessions for dynamic digital content all doubled in reach. Other key performance indicators, particularly those related to commercial and investment activities, also maintained positive trends: More than 70% of payloads launched this year represented projects from the private sector; three new commercially operated research facilities joined the ISS National Lab, including the first-ever U.S. bioprinter in space; and our investor network grew by 25%.

New partnerships and customers in FY19 include commercial entities like Bristol Myers Squibb, GlaxoSmithKline, adidas, and *Scientific American*; nonprofits like the John F. Kennedy Library Foundation; and top research universities like Northwestern—and this growing community augments returning customer activities from organizations like the National Cancer Institute and Hewlett Packard Enterprise, which are interested in building on previous successful flight experiments. Furthermore, more than half of these newly selected projects required no ISS National Lab grant funding to execute project objectives. In total, more than $190 million in external, non-NASA funds are now committed in support of specific ISS National Lab R&D projects—more than half of which is from commercial entities.

This year, research from Goodyear, Johns Hopkins University, Nalco Champion, Scripps Research Institute, The Michael J. Fox Foundation, the University of Washington, and many others were delivered to space, with investigators hoping to uncover new knowledge related to top healthcare burdens for the public and our military servicemembers, pressing environmental and agricultural challenges, and economic hurdles associated with a rapidly changing global technology landscape. Other key FY19 activities include:

- Completion of the first round of experiments from the Tissue Chips in Space collaboration, sponsored by the National Institutes of Health, and the first-ever Rodent Research Reference Mission, which maximizes science return from a traditionally constrained resource.
- Peer-reviewed publications by investigators from the Department of Defense, Novartis, and others—and a granted patent related to increased fungal bioproduction of an antioxidant in orbit.
- Multi-year, repeat collaborations with commercial and non-NASA government entities to augment project funding.
- Three web applications newly for sale online, based on results from an ISS National Lab project in geoanalytics.
- Establishment of an Implementation Partner Consortium—and the addition of three new members to our commercial Implementation Partner community.
- The 8$^{th}$ annual ISS Research and Development Conference, including keynote talks, technical and plenary sessions, investment events, and subject matter expert workshops in tissue engineering, materials science, and sustainability.
- Release of a virtual reality (VR) and video series from TIME in collaboration with Felix & Paul Studios, which documents what it is like to live and work in space, including the first-ever filming of a spacewalk in cinematic VR.
- Educational activities with Marvel, Nickelodeon, and others—many involving in-orbit student experiments.
- Release of a *SciGirls® in Space* video series by Twin Cities PBS, highlighting four female student scientists.
- The first-ever use of CRISPR technology to edit DNA on the ISS—as part of a student project from the Genes in Space program.

We invite you to read the full Annual Report to learn more details about these activities and to understand the context of how ISS National Lab performance indicators and success stories relate to the development of a robust economy in low Earth orbit (LEO).

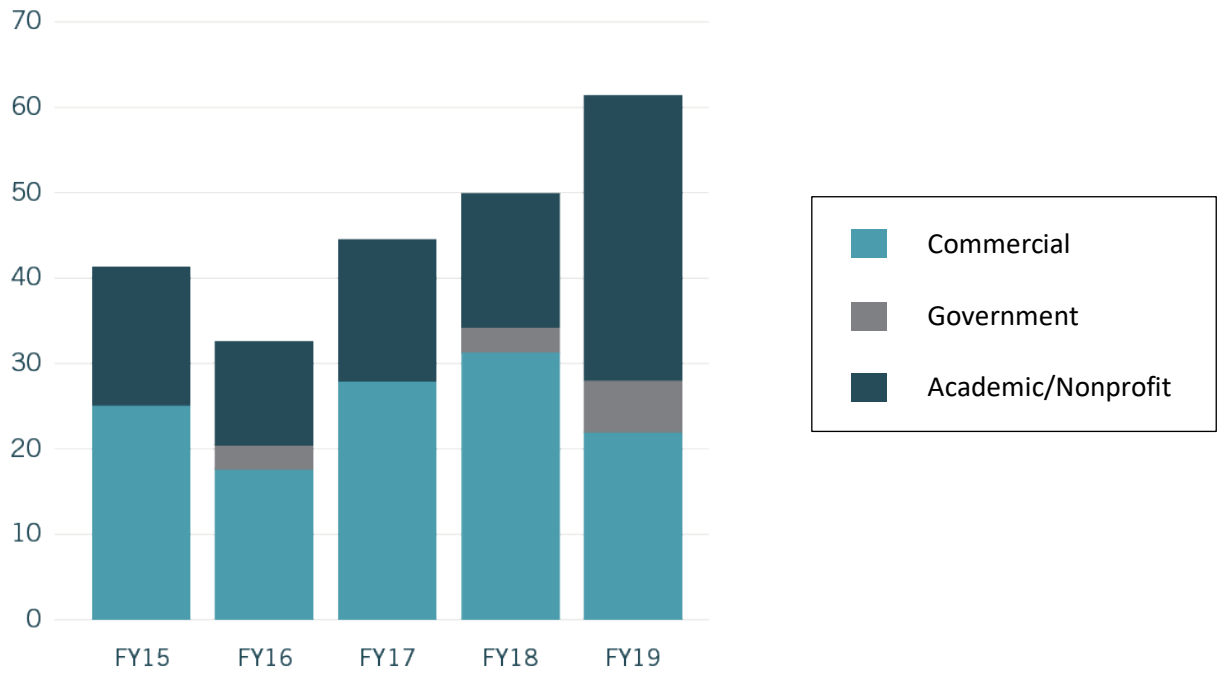
# I. ISS National Lab R&D Portfolio Continues to Attract Investment and Innovation

At a glance:

- The ISS National Lab selected 62 new R&D projects this year, the most ever and a 24% increase over last fiscal year.
- 64% of new projects are from new-to-space investigators, including large multi-national companies like Bristol Myers Squibb, GlaxoSmithKline, and adidas.
- Returning customers like the National Cancer Institute and Hewlett Packard Enterprise seek to build on past R&D successes onboard the ISS National Lab.
- Approximately one-third of new projects are associated with ISS National Lab Rodent Research Reference Missions, which maximize science return from a traditionally constrained resource.
- 74% of new projects are in the Program areas of Industrialized Biomedicine and Advanced Materials and Manufacturing.

In FY19, the ISS National Lab set several all-time records in our key performance metrics (as defined by our Annual Program Plan with NASA). The ISS National Lab continued cultivating innovative R&D ideas from across the U.S., awarding a record 62 projects and programs, a 24% increase over FY18. Of these new awards, 64% represent new-to-space users—also an all-time record.

**Figure 1. Five-year trend in projects and programs selected by the ISS National Lab**




Examples of new-to-space awardees and their objectives include the following.

- **Bristol Myers Squibb** will study protein crystallization kinetics in microgravity to improve drug delivery methods and treatments for diseases such as cancer.
- **adidas International, Inc.** will observe and measure the stationary (i.e., without physical support) spin of a soccer ball in microgravity to improve the aerodynamic design of the ball.
- **GlaxoSmithKline** will evaluate protein stability to improve biopharmaceutical drug development and the treatment of human diseases.
- **Northwestern University** will evaluate fecal samples to better understand the role gastrointestinal microbiota play in overall mammalian health.

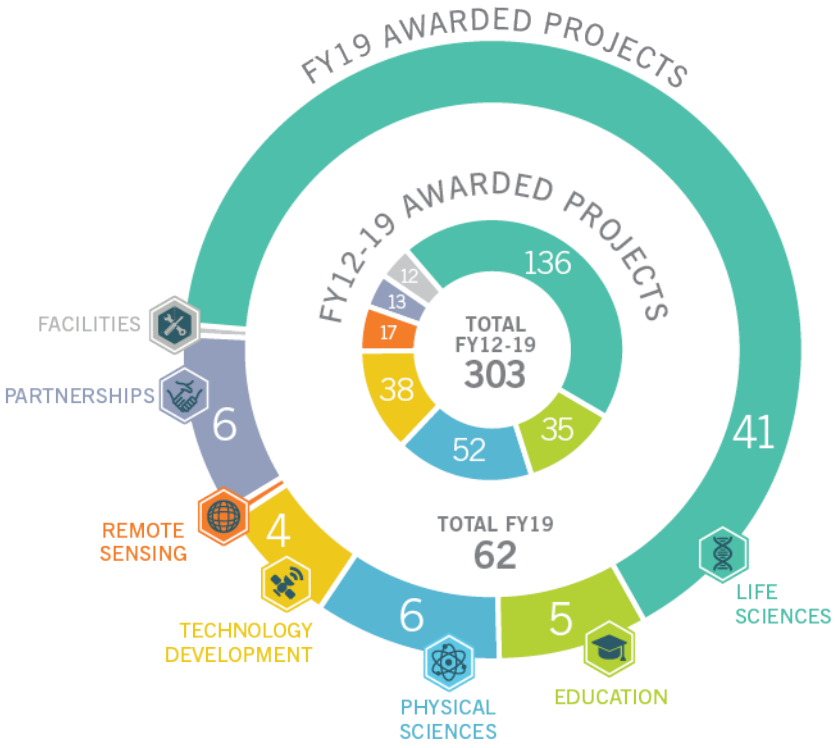
- **The University of Michigan** will investigate mechanotransduction mechanisms of osteoblasts in microgravity to inform research on osteoporosis and age-related diseases on Earth.
- **Arizona State University** will develop and test predictive models of flow between proteins to better understand hydrodynamics and improve drug development.
- **Iowa State University** will formulate a novel computational model intended to provide insight on the bone degradation process, toward improving osteoporosis treatment methods.

Returning users, and their follow-on or new initiatives with the ISS National Lab, include the following.

- **The University of Minnesota** will compare genomic changes in osteoblast cell cultures in orbit, in simulated microgravity, and in normal gravity to determine the mechanisms responsible for accelerated bone loss resulting from skeletal unloading.
- **The National Cancer Institute** will identify how and when structural changes occur during protein crystallization to better inform cancer therapeutics and drug development.
- **The Houston Methodist Research Institute** will investigate the effectiveness and safety of an osteoporosis drug to treat bone loss, using a nanofluidic delivery system in a mouse model.
- **Hewlett Packard Enterprise** will study the performance of a commercial off-the-shelf high-performance computer system over time in the extreme conditions of space.
- **Launchpad Medical** will study if and how suture skeletal stem cells are affected by microgravity to better understand how bones heal after fracture.

These and other new projects continue to expand the R&D portfolio within the areas of life science, physical science, remote sensing, technology development, and student-participant R&D. Additionally, proof-of-concept and technology demonstrations for new facilities promise to continue expanding options for investigators interested in using the ISS for diverse and cutting-edge R&D. Finally, a growing segment of multi-project programs represent agreements with Implementation Partners who recruit and support discrete R&D projects within in-orbit facilities.

**Figure 2. Projects and programs selected by the ISS National Lab**
***FY19-selected and total to date***



The majority of FY19-awarded projects (66%) represent life sciences, including 21 new rodent research projects awarded as part of two research solicitations to support Rodent Research Reference Missions. These reference missions maximize science return from a traditionally constrained resource, allowing tissue sharing among multiple research laboratories. Research using model organisms such as rodents provides insight into not only the effects of spaceflight on astronaut health but also effects that mimic human disease on Earth, such as bone loss, muscle wasting, heart disease, immune dysfunction, and other conditions.

In total, the projects within the ISS National Lab R&D portfolio reflect the multifaceted value proposition of the ISS for advancing terrestrial research questions, and 57% of the all-time portfolio broadly falls within two Program areas formalized in FY19, defined below and described more in Section V.

- **Industrialized Biomedicine Program**: Projects enabling biomedical advancements with a defined pathway for translation from scientific research to industrial or clinical applications, such as new therapeutics, medical procedures, or diagnostic devices.
- **Advanced Materials and Manufacturing Program**: Projects that develop next-generation production methods, improve understanding of mechanisms involved in material transformations, advance fundamental materials discovery, or test processes or manufacturing methods of novel design and synthesis pathways.

The ISS National Lab ramped up efforts to attract new investigations within these Programs in FY19, seeking to maximize the opportunity for science return and tangible applications of research results in healthcare and commercial products on Earth. Thus, of the newly awarded projects in FY19, 74% fall within these Programs.

The ISS National Lab also set a record in FY19 with respect to cost-sharing. Operating as a nonprofit with limited funding for awarding research grants, the ISS National Lab continues to innovate new approaches for efficiently and responsibly allocating these taxpayer dollars to promising R&D initiatives in space. In FY19, ISS National Lab funding was matched more than 9.25 times by committed funding from non-NASA, third-party sponsors and the awarded institutions themselves. In fact, 56% of new projects required only ISS National Lab allocation—no grant funding to support their R&D initiatives. More than $190 million in external, non-NASA funds are now committed in support of specific ISS National Lab R&D projects—more than half of which is from commercial entities. Multi-year, multi-project agreements with government and commercial sponsors represent $53 million of these cost-sharing funds (see Appendix A).

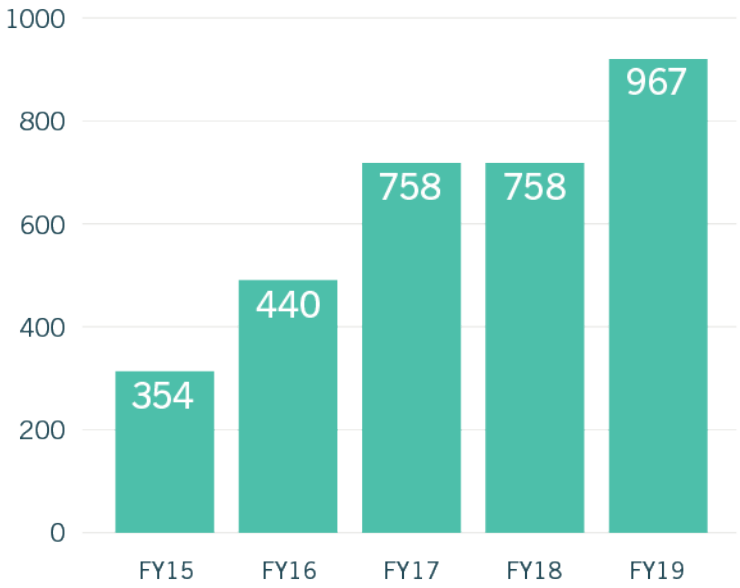
## II. In-Orbit Activities Break Records for Utilization and Showcase Project Diversity

At a glance:

- In FY19, the ISS National Lab set records for the total number of crew-time hours utilized over a single year (967) as well as the total number of crew-time hours utilized in a single increment (708).
- A record 89 payloads were delivered to the ISS National Lab in FY19, an annual increase of 20%.
- More than 70% of payloads (64) delivered to the ISS National Lab in FY19 were from the private sector, representing a broad selection of investigations across diverse sectors.
- Of the payloads delivered in FY19, two included new commercially operated facilities. A third facility was transferred from NASA to the ISS National Lab, bringing the total number of ISS National Lab commercially operated facilities to 17, managed by 10 facility managers.

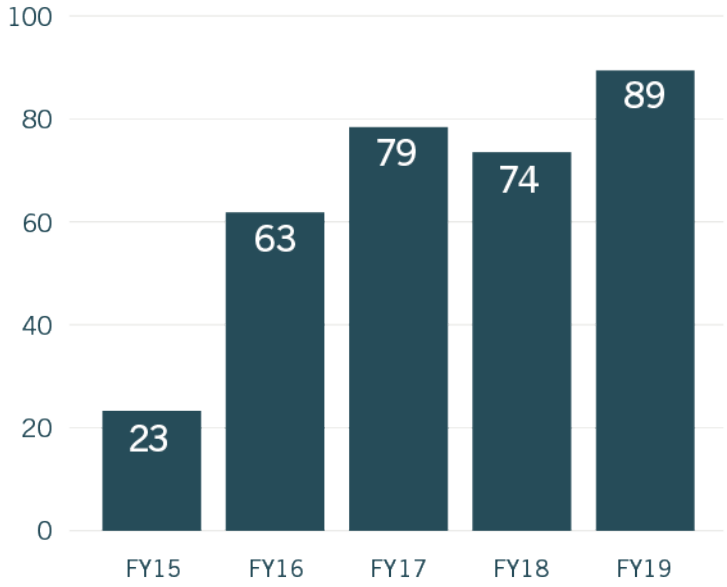
The ISS National Lab continued to maximize utilization and science return in FY19, setting two new crew-time utilization records. In increment 59/60 (March–October 2019), ISS National Lab R&D set a record for the most hours of crew time utilized in a single increment—and the full fiscal year crew-time hours spent on ISS National Lab R&D was also an all-time high.

**Figure 3. Five-year trend in crew-time utilization (hours)**




Record-breaking utilization and science return generate value and positive impact for the U.S. taxpayer. Also record-breaking, 89 ISS National Lab payloads were delivered in FY19, with 72% representing private-sector R&D (including two new facilities discussed below).

**Figure 4. Five-year trend in payloads delivered**




Of these payloads, 36% fall within the ISS National Lab Program areas of Advanced Materials and Manufacturing (16 payloads) and Industrialized Biomedicine (19 payloads). For more information on these Programs, see Section V. Additionally, 34% of payloads were sourced by Implementation Partners (see Section III and Appendix B), illustrating supply-side growth of the LEO economy and the value of new and diverse facilities to support cutting-edge R&D objectives.

Below are selected highlights from payloads launched in FY19 (see many more in Section V).

- Startup company **Cemsica** pursued better methods to design and manufacture cost-effective membranes for use in gas separation technologies at fossil-fuel power plants and in other applications to reduce greenhouse gas emissions.
- **Tympanogen** sought to improve the process of antibiotic release from a novel patch to treat wounds and reduce the occurrence and severity of sepsis, or systemic inflammation.
- **Budweiser** conducted a third research flight—part of a series exploring the effects of spaceflight on barley, a major food source for humans and livestock, in order to produce varieties that are better able to handle stressors such as temperature extremes and water scarcity.
- **Johns Hopkins University** combined basic research with clinical interventional radiology to improve methods for noninvasively following cells in high resolution in humans.
- **Aphios Corporation** examined nanoparticle behavior in microgravity, toward the development of precision-targeted drug therapies designed to treat Alzheimer's and other diseases.
- **Nalco Champion** studied microbial biofilm behavior as it relates to microbial corrosion, toward mitigation of corrosion in oil and gas lines.
- **AstraZeneca** explored ways to advance a nanoparticle drug delivery system for therapeutic cancer vaccines.
- **The University of California, San Diego** conducted the first-ever space-based attempt to study human brain organoids.
- **Scripps Research Institute** studied the stability of the human virome in spaceflight, which may lead to therapies that influence the growth and maintenance of viruses making up a healthy virome and potentially provide a source of new personalized medicine products.

An additional FY19 success story of note includes validation of new late-load capabilities by commercial resupply services (CRS) provider Northrop Grumman, allowing time-sensitive experiments to be loaded into its Cygnus capsule just 24 hours before liftoff. In the past, all cargo was loaded into the orbital capsule multiple days, sometimes even weeks, prior to launch. This late-load capability will double the launch opportunities for ISS National Lab research partners interested in launching investigations that require late load, such as rodent research payloads or other biological experiments, that previously could launch only on the SpaceX Dragon.

For more info on launched payloads, see the following online resources.

- Northrup Grumman CRS-10: www.issnationallab.org/launches/northrop-grumman-crs-10/
- Northrup Grumman CRS-11: www.issnationallab.org/launches/northrop-grumman-crs-11/
- SpaceX CRS-16: www.issnationallab.org/launches/spacex-crs-16/
- SpaceX CRS-17: www.issnationallab.org/launches/spacex-crs-17/
- SpaceX CRS-18: www.issnationallab.org/launches/spacex-crs-18/

## Commercially Operated Facilities

At the close of FY19, 17 commercially operated facilities onboard the ISS National Lab were managed by 10 commercial facility managers. In-orbit commercial facility managers provide ISS National Lab users with operational experience, engineering support, and lab equipment to address user/customer research needs. Two new facilities were delivered to the ISS National Lab in FY19.

- SlingShot, developed by SEOPS, LLC, enables the deployment of CubeSats from Northrop Grumman's Cygnus cargo vehicle after it completes its primary commercial resupply services mission and departs the ISS. Deploying from a higher altitude decreases atmospheric drag on CubeSats and provides a longer operational lifespan. The SlingShot system can also host fix-mounted payloads using Cygnus as a satellite bus for power, attitude control, and communications for longer missions. After undocking, Cygnus moves to an altitude and inclination that are ideal, and the small satellites are launched from the spacecraft to carry out missions that benefit life back on Earth. The demand for small satellites has grown significantly over the last several years due to miniaturization technologies and the availability of deployment from the ISS.
- Techshot Inc.'s BioFabrication Facility (BFF) is the first-ever U.S. 3D bioprinter in space. In its first two years, the initial phase of the BFF will test its ability to print cardiac-like cells. The BFF uses adult human cells (such as stem or pluripotent cells) and adult tissue-derived proteins as its bioink to create viable tissue. Unlike a Russian bioprinting

facility that launched earlier in the year and uses magnetic particles to generate cell clusters, the BFF employs a direct dispensing method of gel materials through four different print heads, similar to methods for 3D printing with plastics. Long-term success of the BFF as a human-organ manufacturing system could enable potential medical breakthroughs including reducing the organ donor shortage (113,000 people are currently on transplant waiting lists) and creating patient-specific replacement tissues or patches.

Additionally, a third facility was transitioned to commercial management onboard the ISS National Lab in FY19. Developed by NASA Johnson Space Center's ISS and Engineering communities in collaboration with the Department of Defense Space Test Program, the Space Station Integrated Kinetic Launcher for Orbital Payload Systems (SSIKLOPS) facility was transitioned to new facility manager Craig Technologies. SSIKLOPS is a satellite deployment mechanism that offers LEO deployment options with minimal technical, environmental, logistical, and cost challenges, widening the variety of payloads possible.

## III. Partnerships Synergize to Power Growth in Supply, Demand, and Investment

At a glance:

- Supply-side activities in FY19 include the establishment of an Implementation Partner Consortium and the addition of three commercially operated facilities to the ISS National Lab.
- To generate ongoing demand for space-based R&D, we continued to support multi-year, repeat collaborations (i.e., Sponsored Programs) with commercial and non-NASA government entities to augment funding for ISS National Lab projects.
- Several new research solicitations complemented traditional business development and Sponsored Programs to build a diverse user base.
- Our investor network grew by 25%, with more than 600 capital introductions made to date.

The ISS National Lab supports R&D with benefit to life on Earth, as well as private-sector activities that support this R&D, to return value to the nation and strengthen the foundation for the growing LEO marketplace. As the most significant global collaboration in human history, the ISS is a thriving proving ground for a variety of partnerships in R&D as well as commercial space. The ISS National Lab enables flexible partnership models that allow organizations to leverage the unique attributes of the ISS that are most relevant to their mission. These include research competitions, investment opportunities, and commercial services expansion. In FY19, continued growth in collaborative efforts helped expand ISS National Lab R&D activities, attract new users, and increase external R&D investment.

### Supply

As access to LEO and the ISS has increased, new private-sector service providers and facility operators have emerged to support the needs of diverse spaceflight R&D users. In January 2012, we began formalizing partnerships with these businesses and are continuing to improve how we facilitate the matching of ISS National Lab users with these providers, also called Implementation Partners.

In FY19 we officially established the ISS National Lab Implementation Partners Consortium, for the purpose of supporting the ISS National Lab in its mission to maximize the use of the ISS to advance scientific research, technology development, and education for the benefit of life on Earth. Consortium members serve as subject matter experts in spaceflight R&D and expert collaborators, sharing specialized scientific, technical, and business expertise that helps inform the activities of the ISS National Lab. Together, the Consortium and ISS National Lab work to expand mutually beneficial business opportunities and collectively advocate the value of the space-based research on the ISS.

Consortium members also had the opportunity to attend two ISS National Lab Implementation Partner workshops, hosted to encourage dialogue and feedback about how we connect users with providers and how we can better enable provider business development activities in the marketplace. Workshop sessions focused on a range of topics, including the utilization of ISS resources, industry trends, and legislative developments.

Finally, new Implementation Partners in FY19 include:

- Aerospace Applications of North America (AANA), which operates the International Commercial Experiment (ICE) Cubes platform, located on the ISS Columbus laboratory—an international, commercially operated, multipurpose facility.
- Craig Technologies, which is now managing an ISS National Lab commercially operated facility (see Section II).
- Rhodium Scientific, which provides support services to life science companies and academic researchers conducting space-based research.

See Appendix B for a full list of ISS National Lab Implementation Partners or visit www.issnationallab.org/implementation-partners.

## Demand

The ISS National Lab is not only a destination for spaceflight R&D; it is a multi-user platform for commerce, education, engineering, science, and technology—for which there is increasing demand. As an innovation platform that can solve big challenges, the ISS National Lab has developed a successful Sponsored Program model that enables sponsor organizations to ask new questions and explore key variables using the ISS as a tool in their innovation portfolio. The model attracts third-party funding (either whole or partial) from private industry, academia, and non-NASA government agencies to support research competitions for projects that seek to use the ISS National Lab to solve cross-cutting challenges.

Evolution of the ISS National Lab Sponsored Program model has resulted in a growing legacy of multi-year partnerships that involve bigger and more innovative collaborations. Many of these public-private partnerships and collaborations focus on addressing key challenges in the Program areas of Industrialized Biomedicine and Advanced Materials and Manufacturing (see Section V for more information on these Programs). Fortune 500 companies, government agencies, and regional incubators have successfully used the Sponsored Program model, which is flexible to meet the needs and budgets of varied partner organizations.

In FY19, multi-year, repeat collaborations with the MassChallenge business accelerator program, Boeing, the National Science Foundation (NSF), and the National Institutes of Health (NIH) continued, bringing the total independent funding committed through Sponsored Programs to date to more than $50 million, which flows either through the ISS National Lab or directly to principal investigators.

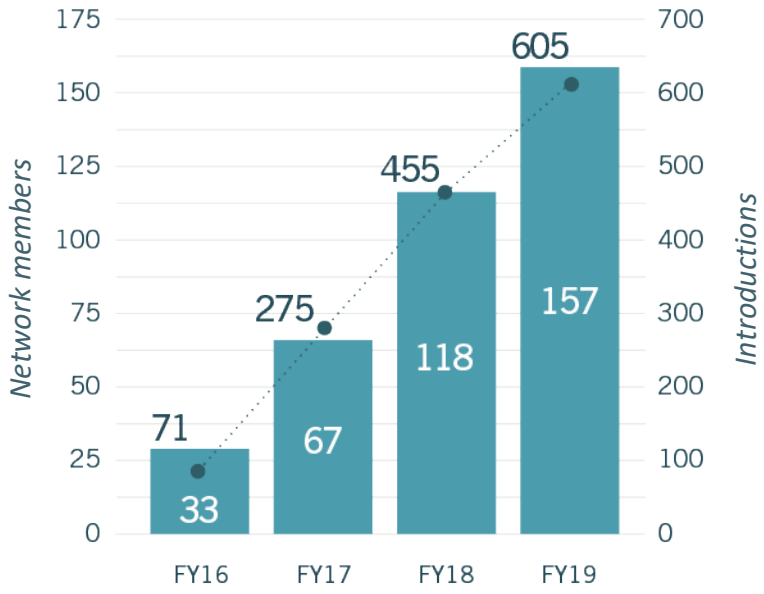
In addition, several formal calls for research proposals in specific R&D focus areas complement traditional business development and Sponsored Programs to build a diverse user base. Through these larger programs and individual outreach to new customers, we are accelerating success for a diverse range of ISS National Lab users, providing tangible return to U.S. taxpayers. For more information on ISS National Lab research competitions, see Appendix A and issnationallab.org/solicitations, and for more information about outreach and stakeholder engagement, see Section VI.

To better streamline use of specific resources amidst this growing demand, the ISS National Lab Resource Utilization Planning System (RUPS) enables optimal use of flight, increment, and facility allocation. RUPS continues to improve its function to compare each resource capability during a defined timeframe against total resources required by all projects in the same time increment—and we continue to refine how we use this information to guide business development efforts toward acquiring projects that fill utilization gaps. Using RUPS, we can adjust our business development targets in real time as research requirements mature, facility options evolve, and the payload manifest grows.

## Investment

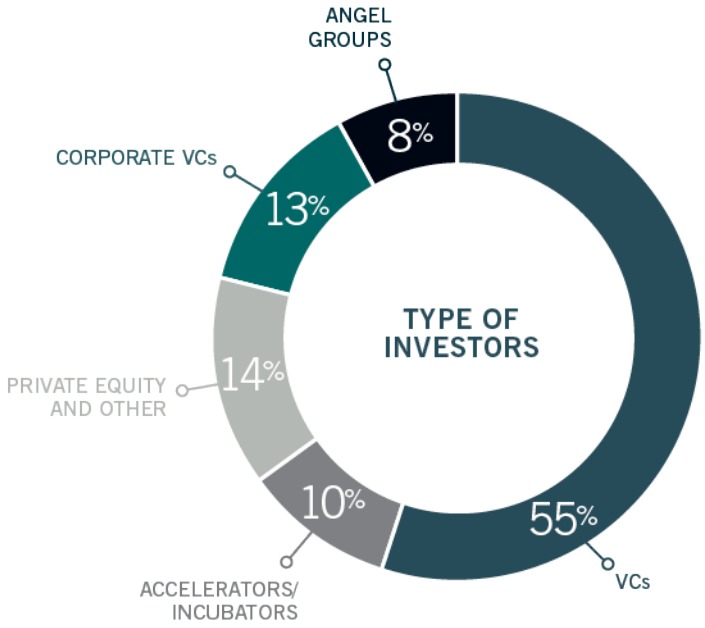
During FY19, the ISS National Lab delivered strong results in the buildout of its ecosystem of private-sector investors—as well as its activities to connect investors with startups looking to do research or develop products on the ISS National Lab and to build out businesses that leverage LEO capabilities.

**Figure 5. Four-year trends in Investor Network activity**




At the end of FY19, the ISS National Lab network included 157 investors, up 25% from FY18. This network consists primarily of venture capital (VC) firms followed by corporate venture investors, angel investor organizations, accelerators, private equity markets, and selected financial intermediaries. We estimate that investors in the network are managing more than $420 billion in assets.

**Figure 6. Investor Network breakdown**



In line with the ISS National Lab's responsibilities to identify appropriate funding sources and match qualified research projects with such funding sources, the ISS National Lab has now made more than 600 capital introductions with venture and corporate investors, connecting these investment entities with 57 companies/startups in the ISS National Lab ecosystem. More than 50% of such introductions were made between summer 2018 and end of FY19, via targeted matchmaking and investor events, including annual Space Investment networking and pitch sessions hosted in conjunction with the ISS Research and Development Conference. The feedback received from the ISS National Lab startup community indicates high value added from such connections, and while not all the resulting funding activity details have been publicly disclosed, our internal estimates indicate that these introductions have supported and complemented financing strategies that have raised an approximate cumulative value of $280 million in capital.

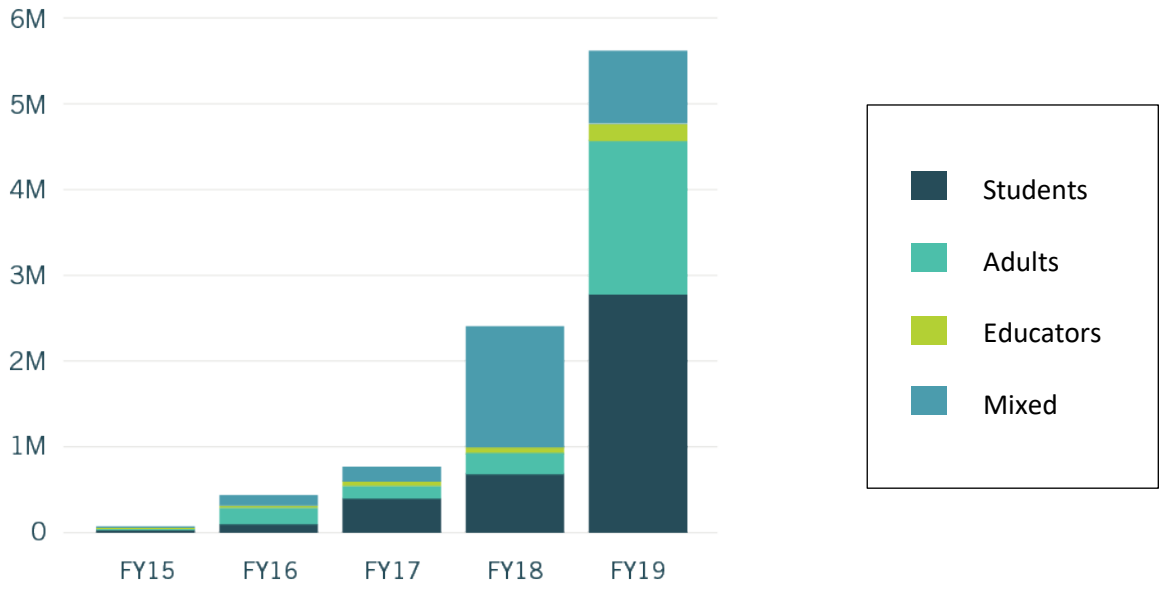
## IV. Space Station Explorers Doubles Reach for Education Initiatives

At a glance:

- For the second year in a row, ISS National Lab educational activities doubled in reach, this year connecting more than 2 million students and more than 5.5 million people in total though 23 partner programs and other initiatives.
- A new collaboration with the JFK Library Foundation complemented FY19 activities in partnership with Marvel, Nickelodeon, PBS, and others—many involving in-orbit student experiments.
- More than 800 educators now volunteer through our Space Station Ambassador program.
- A new STEM educational kit designed by the ISS National Lab compiles free activities that align with national education standards but involve only minimal-cost supplies, helping to broaden use of space-related educational activities in underserved communities.

ISS National Lab education initiatives doubled in their reach again in FY19, showcasing the power of collaboration for engaging students in science, technology, engineering, and mathematics (STEM). Promoting STEM literacy in our country's youth and preparing the future workforce to maintain U.S. leadership in a tech-savvy global economy is a fundamental responsibility of the ISS National Lab, complementing efforts to facilitate innovation in space and support the growing LEO marketplace.

**Figure 7. Five-year trend in education reach**



The success of ISS National Lab education activities is fueled by a growing list of partners and partner programs, listed in Appendix D and shown on the map on Section VI. Since 2012, the ISS National Lab has been building partnerships with schools and educational organizations interested in bringing U.S. STEM achievements to the forefront of the global market. Today, millions of students participate in 23 active programs—education and outreach initiatives with hands-on learning activities associated with the ISS National Lab, many of which launch student-designed experiments to the ISS.

The impressive growth in student engagement over the past five years was paralleled by a shift from viewing ISS National Lab student opportunities as a collection of independent educational activities to managing them as an integrated group of programs that creates a community of learners and explorers. The Space Station Explorers concept reflects the advice of 34 experts in STEM education fields, who outlined the power of a unified approach to maximize program growth and external funding during an ISS National Lab STEM Summit in 2015. Today, the Space Station Explorers brand allowed the ISS National Lab to increase national distribution of STEM opportunities from disparate programs and aided in building a powerful partner network that now includes Marvel, Boeing, the Boy Scouts of America, Challenger Learning Centers, National Geographic Learning, Nickelodeon, and Boys and Girls Clubs, among others. Such high-profile partnerships allow the nonprofit ISS National Lab to secure third-party sponsorships for student activities and elevate overall engagement by leveraging big-brand credibility and expertise.

On the other end of the spectrum, grassroots efforts by ISS National Lab Space Station Ambassadors (empowered educators that receive training and exclusive access to program resources) began in 2013 and now reflect the work of more than 800 dedicated volunteers—more than 300 of which joined in FY19 (learn more at www.spacestationexplorers.org/ambassadors). Several of these Ambassadors tested a pilot concept for a "Space Lab," a physical research area, akin to a biology or chemistry lab, in which students would experience learning activities associated with a blend of resources from the 23 Space Station Explorers programs. This Space Lab pilot program paved the way to a new FY19 partnership with the John F. Kennedy (JFK) Library Foundation. Formed to commemorate the 50th anniversary of the Moon landing and reignite the inspiration of the Apollo program in today's classrooms, JFK Space Labs (www.spacestationexplorers.org/jfk-space-labs-program) is a platform that provides access to ISS National Lab educational activities—including some FY19 educational funding opportunities through Raytheon, Google, and TD Bank.

Other FY19 success stories for STEM education on the ISS National Lab include the following.

- A STEM Kit designed by ISS National Lab staff embraces the concept of "dollar-store science," with free activities that align with national education standards but involve only minimal-cost supplies. The Kit, released in FY19, evolved from a 2016 educator resource guide developed in collaboration with IMAX as a supporting resource for the IMAX film *A Beautiful Planet*. The new iteration of the Kit further elucidates connections with Common Core and Next Generation Science Standards. (Learn more about the STEM Kit at www.issnationallab.org/blog/space-station-explorers-releases-new-kit-designed-to-empower-students-with-knowledge-through-hands-on-activities.)
- Several student investigations launched as part of SpaceX CRS-16. The student experiments on this mission cover a wide range of topics—from examining the ability of fungi to act as a radiation barrier to looking at coffee's effects on oral hygiene in space and studying genetically engineered bacteria that produce medically important proteins. Also launched on this mission were the two winning student experiments from the Guardians of the Galaxy Space Station Challenge. The ISS National Lab partnered with Marvel Entertainment for the challenge, and hundreds of students from across the U.S. submitted concepts for spaceflight experiments based on the physical characteristics of Guardians of the Galaxy characters Rocket and Groot. The winning student experiment for Team Groot is looking at aeroponic farming in microgravity, and the winning student experiment for Team Rocket will examine the effectiveness in microgravity of a dental glue that is activated by ultraviolet light. (Read more at www.issnationallab.org/press-releases/two-student-projects-selected-from-guardians-of-the-galaxy-space-station-challenge.)
- A new video series called *SciGirls® in Space*, part of the popular Twin Cities PBS *SciGirls®* program, highlights four girls who have conducted science experiments onboard the ISS National Lab. The videos provide an opportunity for young girls to see other real-life girls pursuing their passion for science and doing real research on the ISS National Lab. The *SciGirls* television show, website, and educational outreach program is the most widely accessed girls' STEM program in the U.S., reaching more than 14 million girls, educators, and families. The *SciGirls in Space* videos, which are accompanied by standards-based science activities, will be available on multiple PBS online platforms, including PBS Kids, SciGirls CONNECT educator's website, and PBS Learning Media (pbskids.org/scigirls). Twin Cities

PBS is also implementing related educational outreach at five community learning centers across the U.S.: The McAuliffe Center for Integrated Science Learning in Massachusetts, The Challenger Center of Ramapo in New York, The Challenger Center in Heartland Community College in Illinois, the North Dakota Space Grant Consortium in North Dakota, and Girls Inc. of San Antonio in Texas.

- Story Time From Space (STFS) is a Space Station Explorers partner program in which astronauts read children's stories and conduct related science demonstrations from onboard the ISS National Lab. In FY19, STFS partnered with American Girl to record an in-orbit reading of an excerpt from *Luciana: Braving the Deep,* from the American Girl book series. Luciana Vega™—American Girl's 2018 Girl of the Year™—dreams of becoming an astronaut, traveling to space, and someday becoming the first person to walk on Mars. Also part of STFS, the first-ever Arabic book reading on the ISS took place in FY19. The book was read by the first Emirati astronaut to work onboard the ISS, representing growth in the global collaborative nature of the ISS and its ability to support emerging space nations.
- Among the student investigations on SpaceX CRS-18 were 38 separate MixStix experiments developed by young explorers through the Student Spaceflight Experiments Program. MixStix are small mixture enclosure tubes that use clamps to keep fluids or solids (such as chemicals or biological materials) separate until the clamps are released in space to allow the contents to mix. MixStix research on this mission ranged from the evaluation of mold in microgravity to experiments involving water purification and plant biology. The Quest Institute also launched a multi-experiment investigation on SpaceX CRS-18 that involved student teams from all over the world, Magnitude.io launched two investigations allowing students to examine how microgravity influences bacterial growth, and Nickelodeon, the children's television network, sent its iconic slime to space to investigate how microgravity affects the material. The project included a series of science demonstrations to help students learn about basic fluid dynamics.
- A student project from the Genes in Space program made history with the first use of CRISPR (clustered regularly interspaced short palindromic repeats) technology on the ISS. The experiment, designed to provide insight on how DNA repairs itself after damage incurred through cosmic radiation, is the first use of this specific gene editing technique in space. CRISPR holds the potential to combat a variety of global medical and environmental issues. The use of CRISPR in space is just the latest in a trend of advancing genetics tools in space. In 2016, NASA astronaut Kate Rubins sequenced DNA in space for the first time, and the inaugural winner of Genes in Space performed PCR in space for the first time. In 2018, RNA was sequenced for the first time in space, and now with CRISPR, we have hit another milestone that brings us closer to cutting-edge terrestrial genomics. The entire experimental process took place on station—the DNA damage and repair as well as the sequencing to study resulting molecular changes—setting the stage for future DNA experiments that can be conducted on the ISS to expand our understanding of genetics in space.

## V. Key Focus Areas Dominate R&D Progress and Success

At a glance:

- 62 newly selected projects and programs were added to the ISS National Lab portfolio in FY19, with 56% requiring no ISS National Lab funding.
- In total, 141 publications and 5 patents to date reflect results from science in space sponsored by the ISS National Lab, including FY19 publications from the Department of Defense and Novartis.
- Research in tissue chips, rodents, and crystal growth—including FY19 payloads from the National Cancer Institute, The Michael J. Fox Foundation, several major research universities, and biotechnology startup companies—continue to generate demand and produce medically relevant results.
- Projects related to materials science and in-orbit production of materials included research from Goodyear, several projects seeking to produce high-quality optical fibers in orbit, commercial and academic efforts to improve radiation monitoring devices, and healthcare-related projects in bioprinting and retinal implants.
- Research in technology development, environmental sustainability, and other areas complement these growing efforts in our newly formalized Program areas of Industrialized Biomedicine and Advanced Materials and Manufacturing.

In FY19, the ISS National Lab continued progress in several R&D focus areas that have matured alongside growth of the organization and its portfolio. More than 10 ISS National Lab research solicitations were released and/or awarded in FY19, including new rolling-submission solicitations in two overarching program focus areas. Building on eight years of data from project outcomes and customer interest, including partnerships with other government agencies, the ISS National Lab continues to focus research solicitations and business development in key areas with a clear path to translational or applied outcomes that improve life on Earth and/or enable development of profitable industry in LEO. To continue to promote interest and traction in these areas, the ISS National Lab announced in FY19 that two key areas of research would receive programmatic priority over the coming year (and likely beyond). These programs are in Industrialized Biomedicine and in Advanced Materials and Manufacturing. Each of these areas has the potential to establish and strengthen the business case for space within the lifespan of the ISS, lead to meaningful acceleration of the process from basic R&D to application for several fields, and ideally achieve sustainable commercial demand for LEO (and beyond) in key sectors. The ISS National Lab began building a program-based research infrastructure in FY19 around these existing R&D portfolio segments, including the release of two related research solicitations.

## Industrialized Biomedicine

Since 2012, the ISS National Lab has cultivated U.S. public and private interest in and prioritized R&D in biomedical areas with high potential to impact healthcare on Earth. In FY19, we introduced a new umbrella term, "Industrialized Biomedicine," to describe this R&D focus area and to operationalize a Program-level approach to advancing related R&D. Industrialized Biomedicine onboard the ISS National Lab refers to flight experiments that enable biomedical advancements with a defined pathway for translation from scientific research to industrial or clinical applications, such as new therapeutics, medical procedures, or diagnostic devices.

R&D within the Industrialized Biomedicine Program includes but is not limited to:

- Translational or applied research within the medical, biotechnology, biophysics, or pharmaceutical sectors that leverages and advances known science as part of product development.
- Biotechnology design, demonstration, development, and testing with direct terrestrial applications or applications within long-term spaceflight R&D programs that support terrestrial advancements in healthcare or biomedical R&D.
- Fundamental biomedical investigations to establish clear parameters regarding the effects of microgravity within R&D areas with expected market demand for long-term spaceflight R&D programs.

In FY19, the ISS National Lab launched an Industrialized Biomedicine Request for Proposals (RFP) to further stimulate interest in this area from new-to-space investigators and experienced space researchers, particularly those interested in applied or translational research. However, R&D successes in Industrialized Biomedicine are already evident from ISS National Lab projects to date, particularly in the areas of stem cells, tissue engineering, rodent research, and macromolecular crystal growth.

For example, in the area of Industrialized Biomedicine, 141 publications and 5 patents to date reflect results from science in space sponsored by the ISS National Lab. Peer-reviewed journal articles are a critical means to disseminate findings from R&D initiatives and often lend credibility, prestige, and merit to investigators, hypotheses, and even research platforms such as the ISS National Lab. Moreover, a strong publication base often precedes commercial investment in a particular sector. Thirteen new peer-reviewed articles in FY19 formally announced preflight and postflight findings from ISS National Lab-sponsored research. Examples of FY19 peer-reviewed publications from ISS National Lab flight projects in Industrialized Biomedicine include the following:

- The U.S. Army Medical Research and Material Command (Department of Defense) described the effects of bone fracture healing, spaceflight, and the two combined in a rodent model. The results provide insight into how this system can be utilized to expedite the discovery of therapies to treat patients with fractures here on Earth.
- Novartis described how rodent muscle loss in microgravity does and does not mimic skeletal muscle atrophy on Earth. These results are important for the research community that aims to utilize the ISS as a platform to accelerate medical discovery on Earth by using space-based animal and cell models.
- Loma Linda University described spaceflight effects on young and old cardiac progenitor cells. The results demonstrate the beneficial but time-dependent difference microgravity has on these cells and uncovered pathways that might be

exploited to make adult progenitor cells more regenerative, providing a potential therapeutic approach to treat people who have heart attacks.

- Genes in Space student scientists described the procedures and results from in-orbit gene expression studies. The work provides the scientific validation that genetic data can be extracted and analyzed in orbit utilizing miniPCR technology, paving the way for future in-orbit genetic research and crew health monitoring, a capability that may also further validate the ISS as a model for accelerated aging.

Additionally, one new patent granted in FY19 describes actionable results from an Industrialized Biomedicine ISS National Lab project. The patent describes the use of the persistent microgravity environment on the ISS National Lab to enhance the production of a biomedically useful compound called Pyranonigrin A, an antioxidant compound produced by some strains of the fungus *Aspergillus niger*. The joint patent, filed by the California Institute of Technology and the University of Southern California, resulted from an ISS National Lab project led by NASA's Jet Propulsion Laboratory (Pasadena, CA). Secondary metabolites produced by filamentous fungi living in nature are often biologically and chemically active and sometimes have properties that make them excellent drug candidates for the treatment of human diseases. Whole genome sequencing has shown that many genes in the genomes of fungi are not expressed when fungi are grown in the laboratory, as opposed to growing in the wild, resulting in the silencing of many metabolic pathways in fungi under standard laboratory conditions. To study these cryptic metabolic pathways in fungi and unlock their potential to generate beneficial new compounds for drug discovery, scientists have long sought opportunities to expose fungi to novel environments—and in this case, space proved to be key for improving production of a medically useful compound.

For more information on success stories resulting from space-based R&D in Industrialized Biomedicine, visit Upward.ISSNationalLab.org.

### Tissue Engineering

One of the most mature sub-areas of Industrialized Biomedicine onboard the ISS is the broad field of tissue engineering and regenerative medicine, which spans from cell-based studies to organoid growth and 3D printing of human tissues. Regenerative medicine research is aimed at improving health and longevity, using tissue chips and a biofabrication facility to address larger challenges with real-world applications. Tissue engineering has many applications but often includes culturing tissues resembling those in the body to model and study human disease, allow higher-accuracy and personalized drug testing, or advance research in organ growth to address the shortage of organs for transplantation.

Tissue chips are small devices engineered to grow human cells on an artificial scaffold to model the structure and function of human tissues and organs. Because tissue chips are made using human cells and are designed to replicate facets of the physical environment cells experience inside the body, they provide higher-accuracy models. In microgravity, tissue chips have the potential to accelerate pathways for understanding the mechanisms behind disease and developing new treatments. Spaceflight induces changes in body systems that in many cases mimic the onset of health-related outcomes associated with aging and debilitating chronic human diseases on Earth. Thus, spaceflight provides opportunities both for analysis of these rapid physical changes and for testing of therapeutics in accelerated models of aging or disease.

In total, ISS National Lab activities in the area of tissue engineering and regenerative medicine have resulted in almost $30 million in grant commitments from multi-year programs with NSF and NIH, 22 peer-reviewed publications, 47 projects within the ISS National Lab R&D portfolio (supported by eight Implementation Partners), and 19 payloads flown to date (with 10 more planned for FY20). A new bioprinting facility that launched to the ISS National Lab in FY19, detailed in Section II, also showcases expanding capabilities in the area of tissue engineering.

In FY19, initial flights were completed for the first set of tissue engineering projects awarded under a partnership with the National Center for Advancing Translational Sciences (NCATS), which is part of NIH. In 2016, NCATS announced a four-year collaboration with the ISS National Lab to support the use of tissue chip technology for translational research onboard the ISS to benefit human health on Earth. The Tissue Chips in Space initiative is a multi-year, multi-flight program that aims to advance understanding of human diseases, with the goal of translating findings into potential new treatments to improve health on Earth. The collaboration has since grown to include the National Institute of Biomedical Imaging and Bioengineering (NIBIB), also part of NIH. In FY19, the second set of awards under this Sponsored Program was also

announced, and workshops were held at the annual ISS R&D Conference and the annual ASGSR (American Society for Gravitational and Space Research) Conference to discuss tissue engineering and regenerative medicine in space.

The first NIH-sponsored Tissue Chips in Space awardee to fly launched on SpaceX CRS-16 in FY19. The research team from the University of California, San Francisco sought to use tissue chip technology to examine the relationship between immune aging and healing outcomes. As people age, their immune response gradually becomes impaired, resulting in a reduced ability to fight infection and disease. This process may be accelerated in microgravity, as exposure to spaceflight has been shown to lead to immune dysfunction. The research team will investigate the biology of aging by looking at immune function in microgravity and then again during the recovery of the cells after they return to Earth.

On SpaceX CRS-17 in FY19, the remaining four tissue chip investigations funded by NCATS through the first Tissue Chips in Space initiative flew to the ISS National Lab. One investigation from Emulate, Inc. is aimed at better understanding the blood-brain barrier, which could help reveal the mechanisms behind neurodegenerative diseases like Alzheimer's. Another tissue chip investigation from the Massachusetts Institute of Technology is exploring pathways that could lead to new treatments for osteoarthritis, the most common form of arthritis, which affects millions of people. The Children's Hospital of Philadelphia is testing tissue chip systems of the human airway and bone marrow to model how the immune and respiratory systems interact to fight infection. An experiment from the University of Washington School of Pharmacy is aimed at studying tissue chip systems that model the human kidney to gain a better understanding of proteinuria (a condition in which a person's urine contains an abnormal level of protein), kidney stone formation, and the body's use of Vitamin D.

The research team from the University of Washington School of Pharmacy also published an FY19 commentary in the peer-reviewed journal *Clinical and Translational Science* discussing the opportunities and challenges of conducting tissue chip research in space (ascpt.onlinelibrary.wiley.com/doi/full/10.1111/cts.12689). Two additional commentaries in FY19 also focused on the value of the ISS National Lab for advancing tissue chip research. In a *Scientific American* "Observations" article, Dr. Christopher Austin, Director of NCATS, discussed the importance of tissue chip research onboard the ISS National Lab (blogs.scientificamerican.com/observations/tiny-organs-in-orbit); and an article co-authored by ISS National Lab board member Gordana Vunjak-Novakovic published in *Cell Stem Cell* discussed the state of organ-on-chip technology and the value of space to possibly accelerate progress toward the technology's use in personalized medicine (read more at www.issnationallab.org/blog/revolutionizing-medicine-with-organs-on-chips/).

The collaboration with NIH is complemented by related efforts with the NSF Engineering of Biomedical Systems Program, which has collaborated with the ISS National Lab on two joint research solicitations in the areas of cellular engineering, tissue engineering, and the modeling of physiological or pathophysiological systems that could be enhanced through sustained exposure to microgravity. The second of these solicitations was released and awarded in FY19.

### Rodent Research

An additional sub-area of Industrialized Biomedicine with a strong track record for space-based success is rodent research. Scientists have used rodents as model organisms in human health studies for more than 100 years on Earth and for decades in space. Rodents are powerful models to study human disease due to their genetic similarities to humans and their short lifespans, enabling studies on accelerated timescales that have led to their extensive use in preclinical testing for new drugs. Rodent research provides accelerated models of disease for scientists to study the mechanisms behind disease and test new treatments. Space-based research using model organisms such as rodents provides insight into not only the effects of spaceflight on astronaut health but also effects that mimic human disease on Earth, such as bone loss, muscle wasting, heart disease, immune dysfunction, and other conditions. Rodent research on the ISS allows longer-term experiments in this unique environment. To date, 33 ISS National Lab rodent research projects (supported by three Implementation Partners and representing investigators from 14 U.S. states) have produced nine peer-reviewed publications—two of which are detailed earlier in this section.

In FY19, the ISS National Lab implemented a new plan to maximize science return from the high-demand, resource-intensive, and sample-size-limited rodent research program by executing "reference missions," which adapt the standard rodent research format to maximize scientific research opportunities and resource utilization by providing multiple

investigators access to biospecimens from a single mission. As part of their agreement for award of biospecimens, all investigators agree to share their data and publish their results after mission completion. In FY19, the ISS National Lab selected more than 20 projects as part of the first two Rodent Research Reference Missions, solicited via two Requests for Proposals issued in collaboration with the lab animal supplier Taconic Biosciences (which provided rodents for the mission at no cost) and the commercial Implementation Partner BioServe Space Technologies (which contributed to mission operations and biospecimen administration). Both Rodent Research Reference Missions flew in FY19. Insight gained from these missions may help advance research on diseases and aging effects involving muscle, bone, and other organ systems. For more information, visit www.issnationallab.org/blog/rethinking-rodent-research-concept-design.

### Macromolecular Crystal Growth

A third sub-area with robust representation within ISS National Lab Industrialized Biomedicine R&D is macromolecular crystal growth. High-quality crystals of organic molecules, such as proteins, can lead to improvements in drug development, formulation, manufacturing, and storage as well as agricultural solutions that better protect crops and enhance plant growth. In the microgravity environment onboard the ISS, researchers are able to grow crystals that are larger and/or more well-ordered than crystals grown on Earth. Many researchers, including several from commercial entities, are already using the unique crystallization environment onboard the ISS National Lab to advance their R&D. To date, 25 ISS National Lab crystal growth projects (supported by seven Implementation Partners and representing investigators from 13 U.S. states) have produced seven peer-reviewed publications. Of note, external funding (non-NASA, non-ISS National Lab) for ISS National Lab R&D in this sub-area has increased by more than 80% over the past five years.

Example crystal growth projects that launched to the ISS in FY19 include the following.

- **The National Cancer Institute** (NCI) in the NIH studied how and when structural changes occur during protein crystallization to better inform cancer therapeutics and drug development.
- **Frederick National Laboratory for Cancer Research** (sponsored by NCI) crystallized genes associated with cancer-causing mutations to determine new approaches to prevent and treat cancers.
- Startup company **MicroQuin** crystallized a membrane protein found to play a key role in tumor development and survival of breast cancer cells.
- Startup company **Dover Lifesciences** crystallized an enzyme present in muscle and a critical enzyme for glycogen synthesis in the liver together with the enzyme glycogenin, an effort that could lead to the development of drugs to treat obesity, rare genetic disorders, and cancer.

The Michael J. Fox Foundation also launched their most recent crystal growth experiment in FY19. According to more than a decade of research, a mutation in a gene known as LRRK2 (leucine-rich repeat kinase 2) appears to be linked to Parkinson's disease in some patients. However, despite the knowledge that this gene may be involved in some cases of the disease, researchers have been unable to unlock the full potential of this genetic research because of the difficulty in studying its gene product, the LRRK2 protein. The most recent investigation from The Michael J. Fox Foundation used a different type of flight hardware to enable larger crystal growth. Interestingly, the knowledge gained from this and related studies could also be beneficial for those who have Parkinson's disease but do not have the LRRK2 mutation. Even when mutations in other genes may be at fault, many of the symptoms of Parkinson's disease are the same. Thus, treatments developed using the knowledge gained from studying LRRK2 could be broadly effective for the 1 million people in the U.S., and 6 million worldwide, currently living with Parkinson's disease. This research complements other projects in 2019 supported by the National Stem Cell Foundation and the New York Stem Cell Foundation, which are focused on studying three-dimensional models for neurodegenerative disorders using patient-derived, induced pluripotent stem cells with Parkinson's disease and primary progressive multiple sclerosis on the ISS.

New approaches and commercial off-the-shelf hardware for space-based crystal growth continue to be developed and refined to enable expedited, repeat experiments from a growing user base. Also in FY19, an ISS National Lab investigation led by Kristofer Gonzalez-DeWhitt, consultant for The Bionetics Corporation, sought to demonstrate the feasibility of conducting protein crystal growth experiments in real time onboard the ISS. As part of the experiment, ISS crew members added solutions to the protein crystal growth hardware, observed crystal formation using a microscope onboard the ISS, and made adjustments to optimize experimental conditions in orbit. Protein crystallization experiments are usually

launched to the ISS in pre-filled hardware with minimal interaction from crew members, and investigators are not able to check on the progress of the experiment or make any changes while it is in orbit.

## Advanced Materials and Manufacturing

Similar to efforts in Industrialized Biomedicine, the ISS National Lab has been formally supporting R&D in the area of Advanced Materials and Manufacturing since 2012, including flight experiments within the ISS and on exposure platforms attached to its exterior. Projects within this Program area develop next-generation production methods, improve understanding of mechanisms involved in material transformations, advance fundamental materials discovery, and test processes or manufacturing methods of novel design and synthesis pathways. Previous research partners have studied combustion, complex fluid flow, interfacial phenomena, materials degradation, and in-orbit manufacturing, among others. Approximately 10% of the ISS National Lab R&D portfolio falls in this category, with more than 30 payloads launched to date in support of these projects, supported by 10 commercial Implementation Partners.

Earth's gravity confounds precise measurements of the thermophysical properties of materials and their interactions through the effects of convection, buoyancy, sedimentation, and contact with the container in which their properties are measured. Microgravity enables research to observe, model, and exploit underlying physical mechanisms and dynamics that are typically masked by gravity-dependent phenomena in terrestrial studies of combustion, fluids, complex fluids (such as colloids and non-Newtonian fluids), soft matter, and hard materials. For example, breakthroughs in studies related to fluid dynamics, phase separation, and the fundamental internal structure of fluids may accelerate formulation chemistry; nanofluidics technologies; water and energy conservation solutions; enhanced energy generation, transfer, and storage; and development of novel materials and better manufacturing processes on Earth. Materials research in microgravity can also reveal fundamental mechanisms in crystallization, solidification, network formation, and phase transitions that are obscured in Earth's gravity. A deeper understanding of these mechanisms, for example, contributed to the terrestrial development of improved superalloys, stabilized colloid-based products, and better casting processes. Additionally, fundamental and applied microgravity studies may have human health applications; for example, studies on interfacial phenomena promise to advance strategies for prevention of the microbial contamination of food and microbiologically influenced corrosion (or microbially induced corrosion) of materials.

In addition to microgravity, the extreme conditions of the space environment are demonstrably hostile to both materials and the components that they comprise. While Earth-based experiments are often conducted under artificial conditions to simulate extreme operational conditions, space is the ultimate test objective with simultaneous exposure to multiple environmental extremes, providing a mechanism for rapid failure mode and effect analysis.

For information on success stories resulting from space-based R&D in Advanced Materials and Manufacturing, visit Upward.ISSNationalLab.org. Also in FY19, a joint workshop conducted by NASA's Division of Space Life and Physical Sciences Research and Applications (SLPSRA) and the ISS National Lab connected government, university, and industry researchers and engineers interested in using microgravity and the extreme environmental conditions on the ISS to conduct innovative materials research and determining future research topics.

### Advanced Materials

In 2012, the ISS National Lab issued its first solicitation in materials testing and has since released several materials science solicitations, four in collaboration with the National Science Foundation (representing $9 million in grant commitments as part of multi-year programs)—including a new FY19 joint solicitation with NSF focused on transport phenomena (e.g., research from the fluid dynamics, fire dynamics, and combustion communities). The behavior of materials in their fluid state affects the properties of the solid material (e.g., metal alloys and semiconductors used in electronic circuits, optical fibers, and solar cells). In the absence of gravity, fluid behavior is altered, enabling the development of advanced materials and better manufacturing processes for use on Earth.

With respect to ISS National Lab R&D seeking to develop or study advanced materials, 25 projects (supported by nine Implementation Partners and representing investigators from 12 U.S. states) have produced three patents and one product. In FY19, colloid research on the ISS by Procter & Gamble (P&G) resulted in a third patent relevant to product formulation and stability. Spaceflight has been a part of the P&G research portfolio for almost a decade, with experiments

under NASA and ISS National Lab sponsorship studying complex fluid systems under time scales not possible on Earth. The new patent describes proposed improvements related to consumer-product functional characteristics and shelf life. These discoveries are being applied to a new formulation of a current P&G product that has more than $1 billion in annual worldwide sales.

Example advanced materials projects executed onboard the ISS National Lab in FY19 include the following.

- The Goodyear Tire and Rubber Company launched a project onboard SpaceX CRS-18 to develop advanced materials for consumer tires. Goodyear has long demonstrated innovation in space, beginning with the company's key contributions to the lunar landing 50 years ago. Silica is a common material used in consumer tires to help enhance fuel efficiency and traction. While advances in silica technology have been made in many key areas of importance for the tire industry, silica microstructure still represents an area where research would be beneficial. The ISS National Lab investigation from Goodyear will evaluate the formation of precipitated silica particles in the functional absence of gravity onboard the ISS, where the team may be able to observe novel morphologies of silica not previously observed on Earth. Such insights could have a clear path to industrial application in the development of unique silica structures—which could result in enhanced tire performance. A breakthrough in the research of the effect of silica morphology on rubber compound properties could lead to not only significant improvements in fuel efficiency and transportation cost savings but also possibly environmental benefits to advance global efforts toward sustainable living.
- Several companies are using the SUBSA (Solidification Using a Baffle in Sealed Ampoules) hardware onboard the ISS to synthesize materials for use in radiation detection devices back on the ground. Radiation Monitoring Devices, Inc. seeks to synthesize CLYC (Cesium Lithium Yttrium Chloride) scintillator crystals for improved radiation detection devices, and Guardion Technologies aims to improve the synthesis of 2D nanomaterials for use in miniaturized ionizing radiation detectors. Additionally, the Illinois Institute of Technology examined a novel semiconductor material that is nontoxic and more affordable to produce than traditional materials. These SUBSA payloads seek to meet growing technological demands of the U.S. Department of Homeland Security and the U.S. Department of Energy. For example, CLYC scintillators could help minimize the number and types of detection devices needed for military or airport security personnel.

Additionally, an inorganic crystal growth experiment developed by the student winners of the 2018 Wisconsin Crystal Growing Competition launched to the ISS on SpaceX CRS-17. The Wisconsin Crystal Growing Competition is a free educational program available to Wisconsin students in grades 7 and higher, organized by the University of Wisconsin-Madison Chemistry Department's Molecular Structure Laboratory. For the contest, students compete to grow the largest, highest-quality crystal on the ground. Winning students then have the opportunity to test their optimized conditions for Earth-based crystallization against crystallization in the microgravity environment of the ISS.

### In-orbit Production/Manufacturing

With respect to efforts to manufacture materials in orbit, the ISS National Lab R&D portfolio includes seven projects (supported by three Implementation Partners) that have already resulted in more than 17 payloads launched to the ISS National Lab. Within this sub-area of Advanced Materials and Manufacturing, ISS National Lab funding represents less than 5% of total project costs. Commercially operated facilities currently in orbit include an additive manufacturing facility and a newly launched bioprinter (discussed in Section II).

In FY19, two new ISS National Lab investigations focused on ZBLAN optical fiber production on the ISS. These projects—one from FOMS, Inc. and one from Physical Optics Corporation—were preceded in orbit by an investigation from Made In Space, and together these represent efforts by three companies working to demonstrate in-orbit manufacturing of the optical fiber ZBLAN (for more information, see upward.issnationallab.org/the-race-to-manufacture-zblan). Optical fibers are remarkably fine glass or plastic fibers (thinner than a strand of hair) capable of transporting vast amounts of information such as light signals over great distances. There are currently three experiments sponsored by the ISS National Lab focused on the manufacture of a specific kind of optical fiber using a type of fluoride glass called $ZrF_4$-$BaF_2$-$LaF_3$-$AlF_3$-NaF, or ZBLAN. The in-orbit manufacturing promises to produce fibers with fewer imperfections, enabling lower-signal-loss optical communications for applications such as repeaterless transoceanic transmission, sensors used in the

aerospace and defense industries, and improved medical devices (such as laser scalpels). FOMS (San Diego, CA), one of the companies that launched a payload in FY19, holds the first patent for technology to produce ZBLAN fibers in space.

Along with the new bioprinter, other FY19 payloads are also exploring healthcare-related applications enabled by in-orbit production. LambdaVision (Farmington, CT) is leveraging microgravity on the ISS National Lab to improve the manufacturing process for its protein-based retinal implant capable of restoring vision in patients with retinal degeneration, which affects millions of people on Earth. Currently, there is no cure for patients with the two most common types of retinal degeneration—age-related macular degeneration and retinitis pigmentosa—and treatment options are limited. LambdaVision's retinal implant consists of multiple layers of a light-activated protein harvested from bacteria. However, when produced on Earth, gravity interferes with the uniformity of the layers. By taking the manufacturing process to the ISS, LambdaVision hopes to increase efficiency and achieve a higher-quality retinal implant by improving the uniformity and stability of the multilayer system. LambdaVision's investigation is supported by a "Technology in Space Prize"—an award sponsored by the ISS National Lab and Boeing that supports innovative startup companies associated with the MassChallenge program, one of the leading startup accelerators. Working with commercial Implementation Partner Space Tango (Lexington, KY), LambdaVision believes the layer-by-layer approach has potential for manufacturing a number of different technologies—and that in-space manufacturing will be economically feasible.

## Other R&D Focus Areas

In addition to expanding R&D in Industrialized Biomedicine and Advanced Materials and Manufacturing, the ISS National Lab continues to support R&D in other sectors and areas aligned with national priorities. For example, additional areas within which we see continued traction include technology development and demonstration (e.g., use of ISS as a testbed) and projects focused on environmental sustainability.

### Technology Demonstration

The ISS National Lab serves as a destination uniquely suited to test the functionality and durability of various technologies. The microgravity environment, along with extended exposure to the harsh conditions of space, aids in demonstrating improved Technology Readiness Level (TRL) for technologies that either enable space exploration (and impact Earth by creating new opportunities for space-based R&D) or are enabled by space (benefit Earth directly). The space environment serves as a desirable destination to conduct R&D and may facilitate R&D associated with various programs designed to advance early-stage capital for technology, such as the SBIR/STTR (Small Business Innovation Research and Small Business Technology Transfer) programs.

FY19 examples of how the ISS National Lab is de-risking technology demonstration include the following.

- Hewlett Packard Enterprise's Spaceborne Computer returned to Earth after a successful 1.5-year mission. The Spaceborne Computer represents the first long-term demonstration of supercomputing capabilities from a commercial off-the-shelf computer system on the space station. The demonstration will benefit both space-based computing as well as computer systems operating in harsh conditions on Earth. (For more information, see www.issnationallab.org/blog/supercomputing-in-space-hpes-spaceborne-computer-returns.)
- Startup company Orbit Fab successfully completed the first test of its Furphy tanker on the ISS, demonstrating the ability to transfer propellent between two small satellites. Furphy is a compact system for refueling satellites while in Earth's orbit—thereby extending satellite operations. This new tanker technology has two patents pending and went from concept to flight onboard the ISS National Lab within one year. Based on this successful mission, the company raised $3 million in venture capital in the first quarter of FY20.
- SEOPS LLC's SlingShot, a small satellite deployer system, became operational in FY19 (also less than one year from idea to launch). SlingShot enables small satellite deployment from Northrup Grumman's Cygnus cargo vehicle. SlingShot has been used by the Department of Defense, DARPA (the Defense Advanced Research Projects Agency), NASA, and private industry customers including UbiquitiLink. As a result of their technology demonstration, UbiquitiLink has since raised $12 million toward their ultimate goal of providing satellite-based internet and cellular access for devices in areas without ground-based connectivity.
- It has been more than three years since Made In Space, with support from the ISS National Lab to de-risk test objectives, completed a demonstration mission of the first-ever in-orbit 3D printer, the Additive Manufacturing Facility

(AMF). To date the AMF has produced more than 100 tools and other objects in orbit. Made In Space applied lessons learned from the AMF to their current development of multiple additive manufacturing tools anticipated for launch in the coming years, including a bioprinter, a Commercial Polymer Recycling System (CPRS), and other manufacturing platforms for use in microgravity. The CPRS aims to demonstrate plastic recycling capabilities in microgravity, and together with the AMF, will enable semi-closed-loop recycling of used broken parts and excess packaging in orbit into new parts and tools. Made In Space additionally leveraged knowledge gained from these ISS National Lab activities to secure a new FY19 $74 million NASA contract for Archinaut, a program to manufacture and assemble spacecraft components in LEO—to support space exploration and commercialization.

### Environmental Sustainability

The ISS National Lab also provides an ideal platform to evaluate technologies for improvements in ecosystem and atmospheric monitoring, membrane and water purification systems, green manufacturing processes including biodegradable polymers, and agricultural processes as potential solutions for a healthier planet. Sustainability bridges all of the science verticals we support, and related projects comprise approximately 10% of our portfolio, with 31 projects supported by nine Implementation Partners. Of these projects, 60% represent private-sector R&D. A roundtable event at the annual ISS R&D Conference gathered many of these groups together to discuss possible future directions within this focus area—which has already produced four publications and five products from related ISS National Lab R&D initiatives. Three of these products, applications for complex processing tasks based on a prototype that used remote sensing data sets from ISS imaging sensors, are new in FY19.

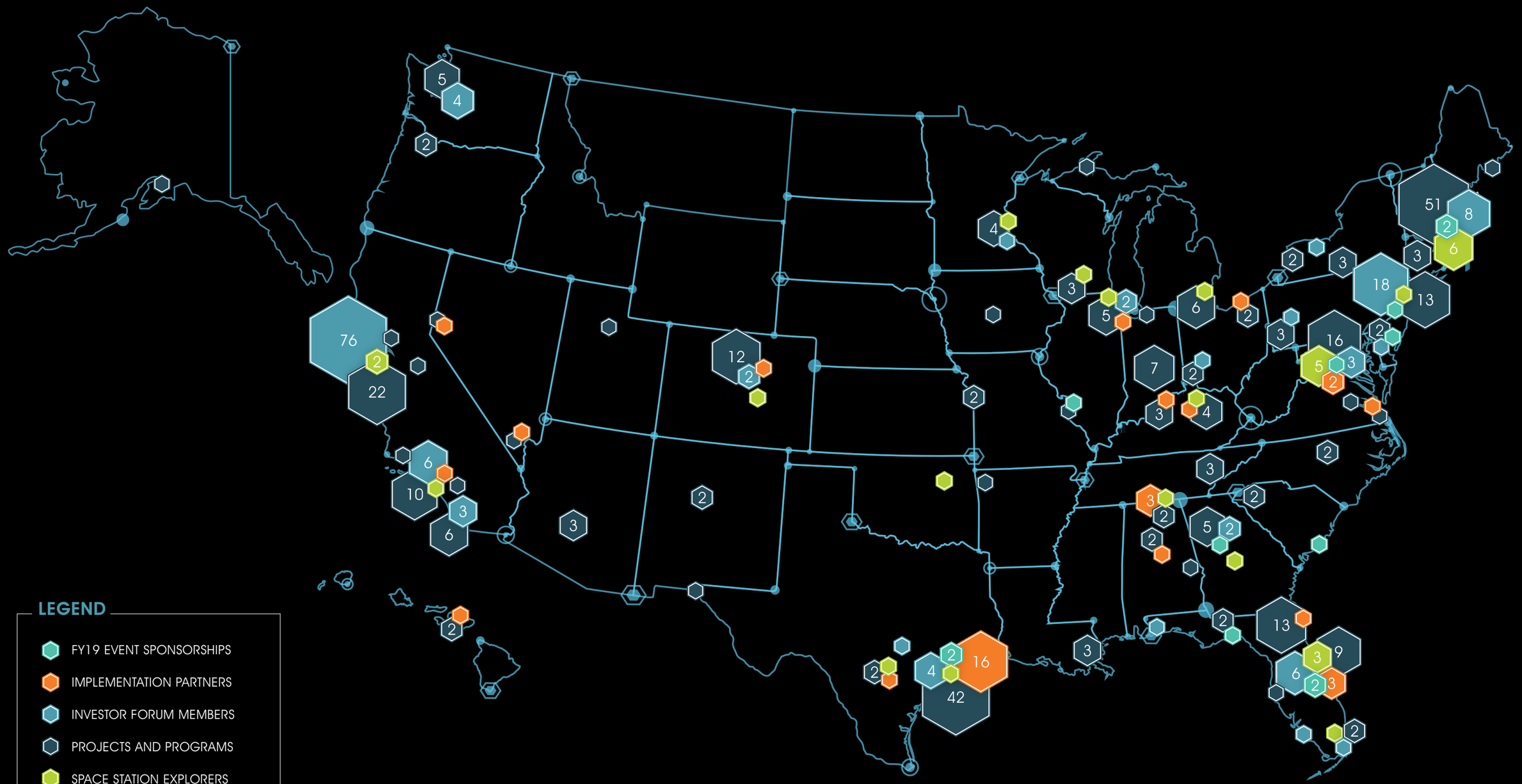
Data generation continues to outpace processing capabilities in the era of LEO democratization. Advances in remote sensing and satellite technology mean that "big data" is making its way into the hands of the larger community. To prepare for the wealth of information that is coming with planned sensors on the ISS, in LEO, and beyond, rapid innovation in computing technology is paramount. Dr. James Goodman of HySpeed Computing developed a web application that combined commercial and open-source software layers into an enterprise system that runs in the cloud, generating results on-demand per the user's request (for more information, see upward.issnationallab.org/constellations-clouds-the-conundrum-of-big-data-processing). Using data from the Hyperspectral Imager for the Coastal Ocean (HICO), which collected more than 10,000 images of Earth during its five years of operations onboard the ISS, Dr. Goodman showed that cloud computing could efficiently deliver the power of image analysis to a global user community. He tested his framework in a proof-of-concept product with customers of Harris Corporation, then expanded to develop several products newly for sale in FY19 through the CloudEO Store, a global marketplace for on-demand geoanalytics:

- VegetationVitality enables users to quickly produce value-added vegetation products and reports applicable to areas such as agriculture, forestry, climate change analytics, logging, and recreation planning.
- WaterExtent provides global insights on the location and quantity of water, critical for human health and welfare, food security, and environmental sustainability.
- LandMask provides a time series of land and other nonaquatic components—such as vegetation, snow, and ice—for coastal change assessment, water quality, ecosystem status or other aquatic and coastal investigations.

Also of note, as a result of their sustainability collaboration with the ISS National Lab, Target Corporation received an honorable mention in business magazine Fast Company's 2019 World Changing Ideas Awards, which recognize businesses, policies, and nonprofit organizations that are "poised to help shift society to a more sustainable and equitable future." The award resulted from the ISS Cotton Sustainability Challenge, sponsored by Target in partnership with the ISS National Lab in FY17, which sought to generate ideas on how the ISS could be leveraged to improve the use of natural resources such as water for sustainable cotton production on Earth.

# ISS NATIONAL LAB ON THE MAP

## A SNAPSHOT OF FY19 ACTIVITIES




### LEGEND

- FY19 EVENT SPONSORSHIPS
- IMPLEMENTATION PARTNERS
- INVESTOR FORUM MEMBERS
- PROJECTS AND PROGRAMS
- SPACE STATION EXPLORERS PROGRAM HEADQUARTERS

# VI. Myriad Outreach and Stakeholder Engagement Activities Span the U.S.

At a glance:

- The 8th annual ISS R&D Conference included keynote speakers NASA Administrator Jim Bridenstine and Dr. Sanjay Gupta, investment-related events, and workshops in tissue engineering, materials science, and sustainability.
- Three Destination Station events in collaboration with NASA provided an opportunity for in-depth brainstorming sessions with academic and commercial entities interested in space-based R&D.
- New organization-specific "pitch events" were piloted as an alternative to traditional research solicitations, promoting crowd-sourcing of innovative ideas for ISS National Lab R&D.
- These in-person touchpoints were augmented by growing digital engagement, with social media engagements and blog user sessions more than doubling in FY19.
- Owned and earned media reach was improved by partnerships with *Scientific American*, Seeker, and TIME.

Alongside the coast-to-coast reach of the ISS National Lab network of partners and investigators (showcased in the map on pages 22–23), ISS National Lab activities sought to expand U.S. engagement using both in-person touchpoints and digital strategies.

## The 2019 ISS Research & Development Conference

The 8th annual ISS Research & Development Conference (ISSRDC), held in Atlanta, GA July 29–August 1, 2019, included dynamic keynote speakers, plenary presentations, technical sessions, workshops, and other activities. Speakers drew attention to projects and programmatic efforts that not only strive to maximize utilization of the ISS National Lab but also reflect our organization's dedication to the development of meaningful focus areas (Industrialized Biomedicine and Advanced Materials and Manufacturing, covered in detail in Section V).

Post-conference analysis of this year's ISSRDC demonstrated overall success in attracting new potential ISS users. Approximately 850 people attended this year's ISSRDC, and 52% of conference survey respondents had not attended ISSRDC in the past, 38% identified their role as researcher, and 92% are considering using the ISS now or in the future. The highest-rated sessions included notable keynote speakers such as NASA Administrator Jim Bridenstine and CNN's Dr. Sanjay Gupta as well as an education-themed session titled "From Skylab to the ISS." The first high school students to do experiments in space worked with NASA and the Skylab space station in 1973. The ISS National Lab tracked down those students, who are now in their sixties, and invited them to share their experiences and the long-term impact on their lives and professional careers, felt even now, 46 years later. The ISSRDC panel consisted of former Skylab high school students as well as students who have more recently conducted experiments on the ISS National Lab, each reflecting on the power of the experience and real or anticipated impact on their lives.

The ISS National Lab also held its annual space-focused startup and investor networking event, Space Investment 2019, at ISSRDC. The session included innovative startup presentations showcasing tangible terrestrial revenue opportunities across the life sciences, medical technology, advanced materials, Earth observation, data analytics, and semiconductor sectors, driving follow-up investor interest in the presenting companies. The event also delivered investor insight on various criteria to access capital from the venture capital community. In addition to the Space Investment event and one-on-one meeting opportunities, ISS National Lab investor activities at 2019 ISSRDC included keynote panel discussions from leading capital market participants from across the funding and investing spectrum, delivering valuable insights on what is driving space investment and highlighting potential areas of opportunity and risk. The 2019 ISSRDC investor events highlighted ISS National Lab's cross-functional capabilities to communicate with and connect financial market participants with relevant innovation and investment opportunities on the ISS.

## Additional Activities

Additional outreach designed to inform and educate also took place throughout FY19. The ISS National Lab orchestrated or collaborated with other entities on various workshops and events.

- A subject matter expert workshop held with the Foundation for Food and Agriculture Research (FFAR) at the Brooklyn Historical Society provided a venue for investors, businesses, researchers, and others to learn about ISS National Lab initiatives in plant science and agricultural biotechnology, toward the potential formation of a research alliance in those areas.
- The annual ISS National Lab Public Board Meeting provided an opportunity for stakeholders, media, and interested members of the space community to receive an overview of recent successes and future opportunities, illustrating the tangible progress made toward full utilization of the ISS.
- The ISS National Lab frequently teams up with NASA throughout the year to visit multiple U.S. cities as part of Destination Station, a free event through which the public engages with astronauts and scientists. These events provide attendees a detailed introduction to the unique R&D capabilities of the ISS National Lab. In FY19, Destination Station Events were held in Austin, TX; Cambridge, MA; and Pittsburgh, PA. ISS National Lab and NASA staff raised awareness of the ISS and increased our reach and involvement with companies such as Philips Research North America and IBM, and academic institutions such as the Massachusetts Institute of Technology and the University of Pittsburgh.
- The annual BIO International Convention attracts leaders from around the world in the biotechnology and pharmaceutical industries. Since 2012, we have met with multiple researchers and companies at this event, resulting in partnerships such as an ISS National Lab project with 490 BioTech that is investigating potential cancer drugs.
- Regular and personal touchpoints with key groups such as the U.S. Congress, the National Space Council, the Office of Management and Budget, and others help us share our experience as it relates to policies or legislation being crafted that will affect the future of the LEO economy. The ISS National Lab is a major component of the LEO Commercialization effort, and not just in operationalizing commercial activity in space by flying private payloads to the ISS—but by facilitating various interactions and process optimizations in the development of a LEO marketplace. These meetings help showcase the value of the ISS National Lab as a thought leader in determining national policy directions in regard to LEO.

Additionally in FY19, the ISS National Lab piloted a new approach to recruiting interesting projects that leverage LEO for innovation to benefit Earth. While formal solicitations garner investigator attention and quality submissions, some organizations are working with us to develop more targeted “pitch events,” organization-specific challenges to find quality project ideas. Similar to a Request for Proposals, a hosting organization puts out notification of an upcoming challenge, and participants submit their concept papers. The concepts are reviewed for quality of science and operational feasibility and the down-selected concepts move toward a live pitch competition. Participants have an opportunity to get information from various sources before putting together their presentation and "pitch" their idea to a panel of judges that include ISS National Lab science reviewers. Winning ideas are selected to complete and submit a final proposal, which then enters the ISS National Lab final determination review process. In FY19, the Mayo Clinic and IBM (with MIT) hosted such competitions and identified a number of candidate projects that are currently finalizing their projects plans. Based on the success of these pilot events, we plan to leverage this event-style competition for larger challenges in FY20.

## Digital & Media Engagement

Throughout FY19, the ISS National Lab continued to deepen its engagement through digital channels by showcasing ISS National Lab activities and the successes and milestones of our partners, users, and affiliates—most frequently through posts on our **ISS360 blog** (www.issnationallab.org/blog) and use of a variety of social media platforms. Both social media engagements (a measure of audience interactivity) and ISS360 user sessions more than doubled in FY19. In total, our social media reach increased by almost 30%, and half of new users to our website were generated based on organic search, demonstrating an increased optimization of search traffic to our content.

Additionally, digital media and partners are extending content viewership, thereby engaging new users, partners, and investors.

- A relationship with ***Scientific American*** was solidified in FY19 with a *Scientific American* article titled, “The International Space Station as a Teaching Tool,” in which two members of the ISS National Lab Board of Directors discuss the power of the ISS as a tool for engaging today’s youth in science. An additional online article by Christian Zur (Executive Director of the U.S. Chamber of Commerce Procurement and Space Industry Council), titled “The International Space Station Is More Valuable Than Many People Realize,” detailed the growth of commercial activities onboard the ISS, including the role of the ISS National Lab.

- The ISS National Lab has continued to develop its relationship with **Seeker**, the popular science content publisher—a collaboration initiated in FY18. The publisher is working with us to highlight research conducted on the ISS National Lab through its digital channel, Seeker Universe. Seeker also is featuring our content on their website, podcasts, and other channels to connect their subscribers with the excitement of ISS National Lab R&D.
- **TIME**, sponsored by the ISS National Lab and in collaboration with Felix & Paul Studios, released a virtual reality (VR) and video series called "The ISS Experience," documenting what it is like to live in space, including the first-ever filming of a spacewalk in cinematic virtual VR. The product was highlighted at the Sundance Film Festival in Park City, Utah. (See time.com/issexperience for more information.)

Additional content authored by the ISS National Lab included the following.

- ***Upward***, the official magazine of the ISS National Lab, released an issue showcasing regenerative medicine discoveries related to heart disease therapy, multisector innovations toward sustainable living, and startup-company advancements in Industrialized Biomedicine. (See upward.issnationallab.org for more information.)
- A report titled "Exploring the Microbiome/Immunome and Disease on the International Space Station—Improving Human Health on Earth," released in FY19, is an overview of the Workshop sessions conducted by the ISS National Lab in conjunction with the 32nd annual ASGSR meeting held in FY18.
- Two articles published in *Apogeo Spatial,* titled "A focus on remote sensing from the International Space Station" and "Lidar from space! Lidar remote sensing on the ISS" reached new audiences.

## VII. Looking to 2020 and Beyond

We hope you found the FY19 Annual Report engaging and informative. As we enter 2020, we near the humbling landmark of 20 years of continuous human presence in space. Much of these 20 years are characterized by impressive growth in the capabilities of the ISS as an orbiting platform for R&D that helps us understand our home planet and prepare for humans to venture further into space. R&D sponsored by the ISS National Lab is a growing and impactful contributor to the legacy of the ISS and its value for knowledge advancement and innovation, as noted in NASA's third edition of the "International Space Station Benefits for Humanity," a compendium of ISS R&D success stories released this year that highlighted 30 success stories from ISS National Lab projects (read more at www.issnationallab.org/blog/international-space-station-benefits-for-humanity-publication-released-today). We look forward to continuing to build a strong foundation of knowledge and technology tools to enable the success of future researchers over the next 20 years and beyond.

In FY20, we will continue development of a program-based research infrastructure for the areas of Industrialized Biomedicine and Advanced Materials and Manufacturing, as discussed in Section V, and we hope to ultimately build a nationwide network that includes Centers of Excellence for Microgravity and Space-Based R&D. We are confident this network will amplify our upward trends in performance metrics by empowering diverse thought leaders and institutions to raise awareness about and promote utilization of the ISS National Lab for R&D with tangible benefit to quality of life on Earth. We will also continue to improve how we serve our partners and researchers, decreasing cycle time from project proposal to selection, relying on data-based decision-making through use and validation of our project assessment methodology, and optimizing utilization via RUPS (see Section III and www.issnationallab.org/ar2018/accelerating-access for more information).

The success of the ISS National Lab parallels exciting developments in the space industry, particularly with respect to commercial activities in LEO. Soon we will have commercial launch vehicles delivering crew members to the ISS from U.S. soil for the first time since the retirement of the Space Shuttle Program in July 2011. We know that the transition to this new commercial crew program will provide additional research time and broader opportunities for discovery for investigators using the ISS National Lab—but we also know the road to success of the program may require delays and adjustments for ultimate success, particularly with respect to FY20 utilization and other supply chain logistics. We are prepared to adjust accordingly and support our partners, investigators, and colleagues in the space community to the best of our ability, embracing our Core Values:

- Passion for the Mission – We are inspired and driven by the ISS and the incredible opportunity ahead of us. We understand and are humbled by what others have sacrificed to build the ISS. We embrace the role that the ISS National Lab plays in shaping the future of space research by maximizing the impact of this incredible laboratory.
- Customer Focus – We are committed to our customers and understand that each and every one of us contributes to the user experience. As the conduits to the space station, we aim to do everything in our power to improve the customer journey and focus on our customer's objectives.
- Teamwork – We believe in the power of inclusion, that there is greater strength in working together to solve complex problems. We collaborate and build networks, harnessing the best ideas from inside and outside the organization. We treat our coworkers, partners, customers, and vendors with respect and appreciation.
- Professionalism – We convey professionalism in all that we do. We communicate openly and transparently and use appropriate channels. We recognize that each employee is an ambassador of the ISS National Lab and contributor to the ISS brand.
- Stewardship – We recognize the great responsibility that we have to maximize the use of the ISS to benefit life on Earth. We demonstrate good stewardship of our resources and put the mission above all else when making business decisions. We are accountable for our actions and expect our users, partners, and vendors to share in these values.
- Commitment to Excellence – We take pride in our work and aspire to be the best we can be. We adhere to the highest standards of our professions and adopt best practices. We embrace new ideas and explore innovative ways of working.

Thank you for your interest in the ISS National Lab and its FY19 progress and accomplishments. We look forward to the year ahead and our continued commitment to foster scientific discovery and technological innovation in space, expand U.S. leadership in commercial space, and inspire the next generation.

Sincerely,

Ken Shields
Chief Operating Officer

# VIII. Appendices *(A–F Available Online Only)*

*To view the full Appendices, visit issnationallab.org/ar2019.*

- *A. Solicitations and Competitions*
- *B. Implementation Partners*
- *C. In-Orbit Commercial Facility Managers*
- *D. The Space Station Explorers Consortium*
- *E. Peer-Reviewed Journal Publications*
- *F. Full Project Pipeline*

## Appendix G: Financials

**Unaudited Summary Statement of Financial Position as of September 30:**

| | 2019 | 2018 | 2017 |
|---|---|---|---|
| Total assets | $3,068,246 | $3,417,124 | $2,073,619 |
| Total liabilities | $721,220 | $618,764 | $415,846 |
| Total net assets | $2,347,026 | $2,798,360 | $1,657,773 |
| Total liabilities and net assets | $3,068,246 | $3,417,124 | $2,073,619 |

**Unaudited Summary Statement of Activities for Years Ended September 30:**

| | 2019 | 2018 | 2017 |
|---|---|---|---|
| Total revenues and other support | $15,796,555 | $19,444,199 | $17,738,180 |
| Total operating expenses | $16,247,889 | $18,303,511 | $17,775,872 |
| Change in net assets | ($451,334) | $1,140,589 | ($37,692) |
| Net assets, beginning of the year | $2,798,360 | $1,657,771 | $1,695,465 |
| Net assets, end of the year | $2,347,026 | $2,798,360 | $1,657,773 |

**Figure 8. Expenses**