



FY19 Annual Report



ECONOMIC DEVELOPMENT
WORKFORCE DEVELOPMENT
APPLIED RESEARCH



The Pacific International Space Center for Exploration Systems (PISCES) is a state-funded Hawaii aerospace center under the Department of Business, Economic Development, and Tourism (DBEDT). The Hilo-based agency is working to position the state as a leader in space exploration while developing sustainable products and technologies that benefit the

State of Hawaii. Through initiatives in Economic Development, Workforce Development and Applied Research, PISCES provides hands-on work experience to Hawaii's future scientists and engineers, preparing them to meet the demands of a highly competitive industry while improving the local economy through job diversification, innovative products and new industries.

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LETTER FROM THE BOARD CHAIR



Henk Rogers

Aloha,

I want to thank those of you in our government who have had the foresight to support PISCES for many years and who understand the value it brings to the State. If we play our cards right, PISCES will soon be the catalyst for a multi billion-dollar Hawaii-based tech industry.

The administration in Washington D.C. has decided that we should go back to the moon before 2024 and build a permanent settlement there by 2028. The cost of building a moon base will be in the hundreds of billions of dollars. This project is called Artemis (Apollo's twin sister) and the state that captures the business of research and development of the moon base will have a new high paying tech job industry. Hawaii can be that state.

PISCES has been working with NASA for several years to find ways to "sinter" powdered lava rock (96% the same as

moon dust) into a building material that has the same characteristics as concrete. The difference between sintered lava rock and concrete is that concrete needs a binder (cement) and a liquid (water) to be formed. Our sintered lava rock requires no binder and requires no water. In fact, we have managed to create a material that NASA tells us is ten times stronger than concrete.

We have the genesis of a new industry. This is the time for the state of Hawaii to show its support. The STEM jobs created by this new industry will enable our talented robotics and engineering students to stay in Hawaii rather than go to the mainland in search of jobs.

In addition to creating technologies for building things on the moon, there are terrestrial applications for this technology. If we can use robots to 3D sinter our lava dust into structures stronger than concrete, we can significantly reduce the amount of imported cement from our construction industry.

These are very exciting times in the space exploration (and settlement) industry. With your continued support, Hawaii can become a major center for NASA's efforts to go back to the moon. We went to the moon to win a space race with the Soviets. This time we go to the moon to stay. This time we will start in Hawaii.

With aloha,

A handwritten signature in black ink, appearing to read 'Henk B. Rogers'.

Henk B. Rogers
PISCES Board Chair

LETTER FROM THE PROGRAM MANAGER

Rodrigo Romo

Aloha kakou,

For the world of space exploration and the global aerospace community, we are living in an exciting time. This year marks the 50th anniversary of the historic Apollo 11 moon landing. When Neil Armstrong first set foot on the lunar surface, everything changed, and a new generation of scientists, engineers and explorers were born. It's been 47 years since humans last set foot on the moon during Apollo 17. Now, NASA has introduced a new program, Artemis (Apollo's twin sister in Greek mythology), to return humans to the lunar surface—this time to establish a permanent human presence. Beginning in 2024, NASA plans to establish a permanent lunar base and gateway to help support future deep space missions. The first mission aims to land near one of the lunar poles where water ice is believed to exist that can serve as an extractable resource for the first astronauts. If successful, Artemis will once again change the face of space exploration and inspire a new generation.

The Artemis program and NASA's renewed interest in returning to the moon have spurred new inquiries about Hawaii's planetary analog sites for pre-flight testing. It has also fueled interest in PISCES' continuing research in basalt sintering for In-Situ Resource Utilization (ISRU) which could enable construction on the moon using native resources.

The last year has also been highlighted by an unprecedented number of milestones and successes in the commercial space industry. After successfully launching three Falcon Heavy boosters, SpaceX received

certification for its flagship reusable rocket which is said to be the most powerful ever built. SpaceX also successfully docked its Crewed Dragon spacecraft to the International Space Station, bringing the company one step closer to enabling



U.S. astronaut launches from home. Blue Origin unveiled its Blue Moon lander intended to carry heavy payloads to the lunar surface as part of a plan to colonize the moon.

In other lunar exploration efforts, NASA awarded contracts to three private companies (Astrobotic, Intuitive Machines and Orbit Beyond) to deliver payloads to the moon, opening the way to space for commercial enterprises.

The small satellite industry is showing rapid growth. As of June 2019, more than 140 companies are developing small launch vehicles for the market. While not every company will be successful, it demonstrates the viability of this industry and also calls forth the need for more dedicated small launch vehicle sites. Worldwide, there is a shortage and Hawaii could fill this niche market by providing a low-earth orbit launch site that could generate sizable revenue for the local economy.

As we move into FY2020, PISCES is excited to continue building upon the successes we achieved during the last fiscal year.

A hui hou,

A handwritten signature in black ink that reads "R. Romo".

Rodrigo Romo
PISCES Program Manager

EXECUTIVE SUMMARY



Building Aerospace & Tech Industry in Hawaii

In June 2012, Governor Abercrombie signed Act 169, SLH 2012 which transferred the Pacific International Space Center for Exploration Systems (PISCES) from its position under the University of Hawaii at Hilo and instituted it as a State project within the Department of Business, Economic Development and Tourism (DBEDT), administratively attached to the Office of Aerospace Development. The bill recognized PISCES, including its proposed aerospace technology research and development park project, "as an economic driver for the island of Hawaii that promotes the establishment and growth of new sustainable and green industries along with associated jobs, workforce development, internships and science, technology, engineering and math education programs".

The aerospace research and development park project has now evolved into two projects, each of which has migrated to other management domains.

Under the Department of Labor & Industrial Relations, the PISCES research & development park project was broadened to include the astronomy industry and renamed the Multi-Purpose Processing Facility (MPPF) to support the Astronomy and Aerospace industries. Now referred to as the Innovation & Manufacturing Center (IMC), the project is being spearheaded by the Hawaii Technology Development Corporation. PISCES is a member of the IMC working group that conducted a feasibility study for the IMC that shows promising results. With PISCES participation, the IMC working group

continues to meet and steer the execution of the planned facility.

While the IMF addresses the technology research and development park aspects of the original legislative vision for PISCES, the aerospace and analog site aspects have been undertaken by a private sector group with driven leadership: the International Moonbase Alliance (IMA). PISCES participated in IMA's inaugural International Moonbase Summit in 2017— a conference well-attended by respected scientists, educators and engineers from space agencies and industries worldwide. At this time, the IMA remains active in pursuing its vision to build a prototype lunar base on Hawaii Island that will support a future lunar settlement.

PISCES continues to address the aspirations of the bill under which it was reassigned to DBEDT. Since focusing its core objectives, PISCES has seen significant results and will continue to work within three interconnected areas in the interest of developing and strengthening Hawaii Island's economic environment for aerospace and other technical fields. These areas include applied research, workforce development and long-term economic development.

Advances in technology and the support of private investors has transformed Space Exploration into a vibrant and growing economy. The areas of rapid growth include small satellite manufacturing, small satellite delivery vehicles, small satellite launch facilities, space tourism, advanced manufacturing, materials science, robotics, Mars/Lunar habitat research & development and In-Situ Resource Utilization (ISRU).

COMPANIES EMPLOYING
FORMER PISCES INTERNS



NO. OF STUDENTS
MENTORED SINCE 2013



OUTREACH EVENTS
SUPPORTED IN FY19



NO. OF PEOPLE REACHED
THROUGH OUTREACH



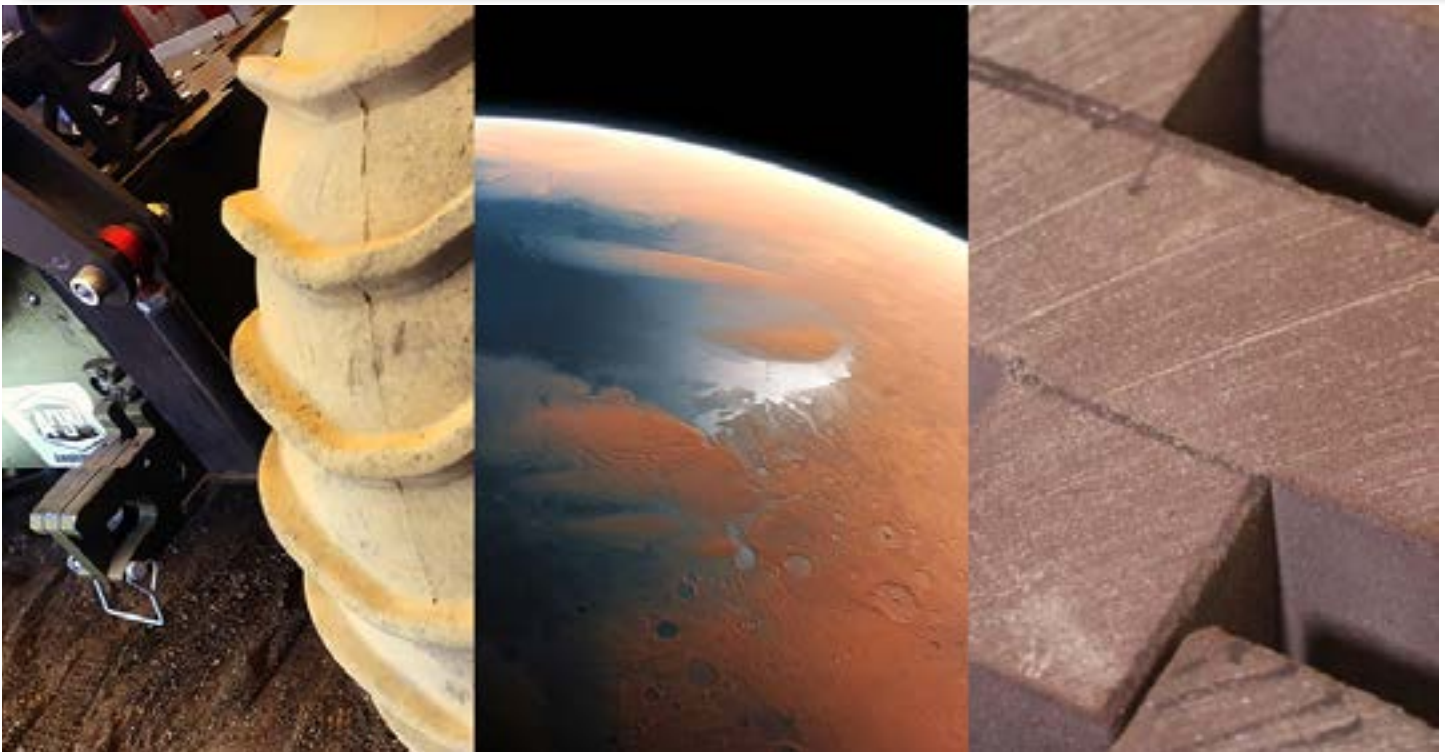
GLOBAL MOU
PARTNERSHIPS



NASA's new Artemis program, which aims to send the first woman to the moon and establish a permanent settlement, is an aggressive program that has resurrected interest in ISRU— an area that PISCES has gained a strong reputation for through its research in sintered basalt. There is also a renewed interest in the analog test sites on Hawaii Island for testing technologies to return to the moon and PISCES has a unique opportunity to engage and support this global interest.

CORE OBJECTIVES

ECONOMIC DEVELOPMENT



Support for the Private Sector

One of the most important roles for PISCES is to support growth and development in the private sector through initiatives in long-term economic development. PISCES employs two main approaches in these efforts. The first is to actively encourage commercialization of the agency's research products through private investments that can generate new business and employment opportunities in Hawaii. For example, PISCES' research in basalt sintering methods and continuous basalt fiber manufacturing provides valuable new information about Hawaiian basalt characteristics, manufacturing processes and proof of concepts that can attract entrepreneurs. The second

approach is to serve as a local liaison for projects or companies interested in entering the Hawaii market. Examples of these projects include a small satellite launch facility in East Hawaii and a laser-based ground communication station to support space operations.

Long-term economic development projects take years to develop and PISCES helps facilitate the growth of these initiatives by guiding and supporting companies and organizations who will bring new business opportunities to Hawaii. During FY19, PISCES has been involved in coordinating and supporting four long-term economic development projects as follows.





Sintered basalt tiles are made using raw basalt fines with no additional additives.

Basalt Manufacturing

Sintered Basalt Blocks, Bricks & Pavers

PISCES has been researching sintered basalt as a technology for space exploration infrastructure and as a locally sourced building material for several years. In 2016, PISCES partnered with NASA's Kennedy Space Center (KSC) to develop sintered basalt pavers for a Vertical Take-off/ Vertical Landing Pad project. Since then, PISCES has built upon the results of this project, developing two different materials with exceptional property structures.

These materials were created using the same raw basalt fines, but were sintered at different temperatures (2,100 °F and 2,150 °F) which yielded different results. NASA KSC performed structural analysis on the materials and found that the 2,100 °F material possesses a higher flexural and compressive strength than residential concrete (and nearing commercial concrete). The material sintered at

2,150 °F exceeded the strength of specialty concrete.

Due to its high durability, the 2,150 °F materials has drawn interest as a product for commercialization. PISCES is currently working with two groups of investors who are interested in bringing the material to market.

Technology: The prototype sintered basalt tiles were manufactured using fines from a local quarry with no additives or aggregates. The basalt was placed in a ceramics kiln and sintered at 2,150 °F. PISCES technicians are working to streamline the process and create a consistent, reliable product. One method under investigation is the use of a binder to sinter without a mold. If successful, the process can be extended and used to manufacture high volume, simple-shaped forms for construction materials like slabs, tiles, bricks, block and floor pavers. Sintered basalt materials provide an extremely high degree of thermal insulation protection.



Basalt fiber fabric.

Basalt Fiber Manufacturing

In 2018, the basalt fiber industry was estimated to be worth \$178 million. It is expected to grow to \$400 million in the next 10 years. While it remains small, the growth of the basalt fiber market is projected to far surpass fiberglass and carbon fiber. Investing in the industry now could yield a highly profitable return.

Basalt fibers are created by extruding basalt and forming fine filaments that have similar, if not stronger, properties than fiber glass. These fibers can be used to manufacture basalt rebar (they are stronger and lighter than steel rebar and resistant to corrosion), basalt fiber, tape and mesh.

Preliminary findings show that some of Hawaii's basalt has the proper chemical composition needed to create basalt fiber. Currently, only a few locations in the world are producing it including plants in China and Russia.

Given the high cost of shipping materials to Hawaii, manufacturing

basalt rebar locally would benefit the state with a sustainable new product. The product would be derived from local resources and also withstand corrosion from the local environment better than its alternative, steel rebar.

In 2018, PISCES funded a market feasibility study for a continuous basalt fiber manufacturing facility in Hawaii County. The study found that a 6,600 metric ton plant would produce approximately \$1 billion in free cash flow and \$450 million in net income over a 30-year operating period. The initial capital investment for the plant was estimated at approximately \$80 million. The study also reported that such a plant would create about 80 jobs with an average annual salary of \$75,000. PISCES is currently working with a Texas firm to determine the quality of fiber that Hawaii's basalt can produce. PISCES is also seeking investors interested in developing the project into a private enterprise.

Small Satellite Launch Facility

Costly, large single satellites are being replaced by smaller, cheaper, lighter satellites in constellation formations. These constellations support communications, weather monitoring and Earth studies. Where large booster rockets have traditionally launched large, single satellites, these same boosters can now launch many small satellites at once, or use small boosters to launch numerous small-satellites at a lower cost.

Roughly 140 companies are currently working to develop small launch vehicles that can service payloads ranging from 50kg up to 1000kg. While not every company will successfully enter the market, their efforts provide insight into the demand the industry is anticipating. One of the biggest challenges small vehicle launch companies like Rocket Lab are facing is a shortage of dedicated launch facilities. As more vehicle companies enter the market, the need for launch



Above: RocketLab's small satellite launch facility in New Zealand provides an example of what such a facility in Hawaii would look like in terms of size and infrastructure. Left: A "cubesat" small satellite is among the types of payloads a small satellite launch facility could send into space.

sites will grow accordingly.

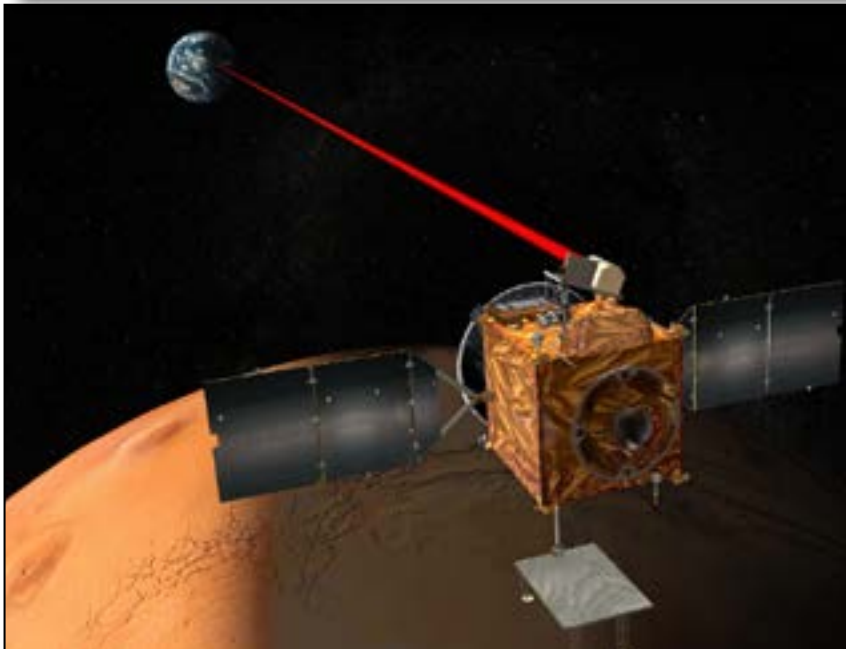
The interest of public and private sectors around the world to establish a small vehicle launch facility in Hawaii is real and it could significantly benefit Hawaii's economy. Such a facility would help diversify the local economy and create new STEM-related jobs.

Hawaii, and specifically the Island of Hawaii, has a unique competitive advantage given its geographic location making it an ideal site for equatorial launches. PISCES is part of a team of advisors working with a private launch company

interested in building and operating a spaceport in Hawaii. The project is currently undergoing an environmental assessment to determine if the site of interest presents any potential problems to local flora, fauna and areas of cultural significance.

The spaceport could also act as an aggregator to develop an aerospace industry cluster around its operations. This cluster could include test and assembly facilities for small launch vehicles, small satellite manufacturing, electronics and communications shops, specialized machine shops, 3D printing shops and more.

ECONOMIC DEVELOPMENT



Laser technology for space communication provides the equivalent upgrade speed of dial-up to broadband internet.

Laser Communication Station

Between 2016 and 2017, PISCES partnered with NASA to oversee two comprehensive studies conducted at NOAA's Mauna Loa Observatory site. NASA has been interested in establishing a ground-based laser

communication station in Hawaii that would allow transmissions in space at much higher rates than conventional RF communication systems. The study's results showed that Mauna Loa provides an ideal location for such a station.

In July 2017, *SpaceNews* published an article about a private company that intends to establish a global network of ground-based laser communication stations. One of their favored sites is in Hawaii. PISCES contacted the company in July 2017 and have been working with them to get access to the site they identified.

The technology developed through this project will enable satellites to send and receive data from Earth at 10 Gbps and more than two terabytes per day. Current data transfer rates through RF transmissions are 50 to 100 Mbps. The upgrade in bandwidth is the equivalent of going from dial-up to broadband internet.

MOU Partnerships in FY19

- ISERI
- Na Pua No 'Eau
- Hawaii Techworks
- Russ Ogi
- CRAFT
- ISTVS
- UNSW ACSER
- Planetary Power
- Ontario Drive Gear
- HoneyBee Robotics
- Made In Space
- Jenoptik Laser Technologies
- NOAA
- Center for Advanced Materials
- NASA SwampWorks
- Google Lunar XPRIZE
- 'Ena Media
- Solvi Energy S.A.
- Hawaii Community College
- RedWorks
- Bolton, Inc.
- Shark Wheel
- Caterpillar, Inc.
- Canadensys
- NELHA
- SpaceFactory, Inc.

CORE OBJECTIVES

WORKFORCE DEVELOPMENT



A high school student programs a smart robot she built during the PISCES Women's STARS Program.

Unique Opportunities for Hawaii's Next Generation

Hawaii has largely shifted from an agriculture- to a knowledge-based economy in the last 30 years. According to the State DOE's 2011-2018 Strategic Plan outline, living-wage jobs are now largely based on skills and knowledge in Science, Technology, Engineering and Math (STEM). The demand for these jobs is expected to grow. Projections show technology jobs will lead Hawaii's economy in growth, adding more than 3,000 new jobs between 2011 and 2021 (DBEDT, EMSI).

PISCES is actively working to prepare Hawaii's youth to meet this growing demand through several

Workforce Development initiatives that provide resources, encouragement and hands-on experience in STEM and aerospace related fields. These include summer and credit-based internship programs, STEM career camps, youth robotics programs and support for numerous outreach activities throughout the year to inspire and engage local youth in aerospace and technology. Through these activities, PISCES aims to prepare the next generation of scientists, engineers, programmers and technology specialists for the careers of the 21st century.

WORKFORCE DEVELOPMENT



PISCES Intern Kye Harford uses a wetsaw to cut a block of sintered basalt into tiles.

Internships for Hawaii-based College Students

PISCES offers both paid and credit-based internships to college-level students based in Hawaii. Participating students are challenged and mentored in aerospace projects in Robotics and Materials Science, applying their classroom knowledge while developing new skills that will set them apart for future career opportunities. Students are assigned specific project goals and must work both in teams and individually to meet deadlines and complete their assignments. Interns are also allowed the flexibility to bring their own creativity and ideas to projects. In addition, PISCES partners with Akamai Workforce Initiative and PIPES to provide work experience to eligible students. Internships are offered in two tracks related to aerospace development: Robotics and Materials Science.

Robotics

The Robotics internship track serves as a platform to develop students' resumes and to make connections in the aerospace industry. Robotics interns hone their skills in electronics technology, software programming and hardware engineering through hands-on work with PISCES' planetary analog rover, Helelani.

Once students design and implement their projects with the rover, they test the results through a Design Reference Mission field test at a planetary analog site.

Since 2014, 17 students have worked with Helelani, upgrading its software and hardware systems, communication capabilities, imaging and mechanical systems, graphic user interfaces and sensors. Several



NO. OF STUDENT INTERNS
SINCE 2013

 44

COMPANIES EMPLOYING
FORMER PISCES INTERNS



former robotics interns have gone on to work for companies like Google and Microsoft, and most recently, NASA's Jet Propulsion Laboratory to develop systems on the Mars 2020 rover.

Materials Science

The Materials Science internship track incorporates principles of geology, volcanology and planetary science for applied research projects. The program is designed to instill confidence in students and give them hands-on experience doing scientific research. Students learn field testing, chemical and mineral analysis, lab and field safety. Students also learn to hone their scientific writing skills and have the chance to co-author a scientific research paper on their work.

Each year, Materials Science projects are tailored to meet individual students' needs and skillsets. During FY19, interns characterized lunar and Martian planetary analog sites on Hawaii Island, collected and analyzed samples and sintered them to determine their effectiveness as ISRU materials.



Top: PISCES/Akamai Intern Kylie Higaki gives a final presentation discussing her research on basalt sintering. Middle: Robotics interns stand at a computer behind the Helelani planetary rover at the PISCES robotics lab. Bottom: Former intern Aaron Roth configures a stereoscopic camera for the rover to capture 3D images. Roth was hired by NASA JPL after graduation to work on the Mars 2020 rover.

WORKFORCE DEVELOPMENT



Women's STARS Program

Women are largely underrepresented in STEM-related careers and currently account for only 22% of employees in the top three in-demand STEM jobs in Hawaii (Hawaii Industry Sectors). One of the possible reasons behind this disparity is young women interested in STEM may feel isolated and have fewer role models and mentors than young men. Only 4% of female students interested in pursuing STEM are encouraged to do so by a mentor; 20% of current female high school students interested in STEM say they would like to learn more about mentoring and motivational programs to help prepare them for the future (Million Women Mentors).

PISCES' Women's STARS (STEM Aerospace Research Scholars) Program aims to address this problem while also meeting the need for a larger STEM workforce in Hawaii. STARS is a week-long space and science camp held each summer. The program accepts up to 12 eligible high school girls from anywhere in the state

and includes meals, accommodations and on-island transportation. The key elements of the program include:

- Behind-the-scene tours at some of Hawaii's leading scientific research and education facilities including HI-SEAS, NELHA's Hawaii Ocean Science & Technology Park, 'Imiloa Astronomy Center, Maunakea Observatories and the USGS Hawaiian Volcano Observatory;
- Interactive presentations and activities with leading women in STEM;
- Hands-on problem solving workshops in robotics and engineering;
- Group projects and discussion groups;
- Connections with internship opportunities including Akamai Workforce Initiative, Maunakea Scholars Program and NELHA volunteer positions;
- Exposure to female role-models and mentors.



The STARS Program will move into its seventh year in FY 2020. In FY 2019, the program received \$15,000 in supplemental funding including a \$10,000 donation from Caterpillar, Inc. and a \$5,000 grant from Hawaii Community Foundation’s Career Connected Learning Program.

By current measures, the STARS Program is meeting its goal to encourage young women in STEM. Feedback surveys from the 2019 program show 100% of students want to pursue a career in STEM after attending STARS. Follow-up surveys are in progress to follow the path of former STARS students and learn the long-term impact of the program on their education and career goals.

Since it began in 2014, STARS has expanded each year, providing a more in-depth curriculum and experience to participating students. The program now offers overnight accommodations so students from other islands may attend. STARS is largely made possible through a growing number of partnerships with STEM-related organizations and companies.

Left page: Students spent a night on “Mars” at the HI-SEAS habitat on Mauna Loa during STARS in 2019. Above left: Halia Buchal, a North Hawaii STARS student, holds the smart robot she built and programmed during a robotics workshop. Above right: STARS alumnus Naomi Schubert views coral reef upclose at Legacy Reef Foundation.

FY19 SPONSORS

- Caterpillar, Inc. - \$10,000
- Hawaii Community Foundation - \$5,000

PARTNERSHIPS

- Hawaii Science & Technology Museum
- Canada-France-Hawaii Telescope
- EAO/James Clerk Maxwell Telescope
- ‘Imiloa Astronomy Center
- NASA
- HI-SEAS (Hawaii Space Exploration & Analog Simulation)
- NELHA
- Legacy Reef Foundation
- Ke Kai Ola Marine Mammal Center
- Hawaii State DLNR
- USGS Hawaiian Volcano Observatory
- University of Hawaii at Hilo

WORKFORCE DEVELOPMENT



OUTREACH & EDUCATION

As part of its commitment to Workforce Development, PISCES is actively involved in community outreach and education to inspire and engage local youth and the community at large. Each year, PISCES staff participate in and support dozens of local science, engineering, astronomy and robotics events to encourage, educate and inspire students to stay curious about the world they live in and accomplish their highest aspirations in education and work.

Photo above: Kyla Edison presents a public talk on human Mars exploration at the 'Imiloa Astronomy Center's Maunakea Skies talk series.

During FY19, PISCES participated in 40 outreach and education events with activities themed around space exploration and planetary science. These activities reached roughly 7,000 people in schools and the local community.

TOP OUTREACH & EDUCATION EVENTS IN FY19

- First Lego League Kick-Off
- Vex IQ Robotics Competitions
- CFHT Manufacturing Day
- AstroDay West Hawaii
- AstroDay East Hawaii
- Onizuka Science Day at UH Hilo
- Hawaii CC Career Fair
- Keaukaha Ohana Science Night
- HAAS Science Expo
- Pahoia Science Night

TOTAL EVENTS & PROGRAMS SUPPORTED IN FY19

 40

PISCES-RISE Robotics Program for Keaukaha Youth

In 2018, PISCES partnered with PUEO's (Perpetuating Unique Education Opportunities) RISE program in Keaukaha to bring an after school robotics program to elementary students. With a grant from Hawaii Community Foundation to purchase VexIQ robotics kits, the PISCES-RISE Robotics Team was born.

Keaukaha students responded enthusiastically to the program and excelled in their building and programming skills. The team is supported by student mentors from UH Hilo. Now moving into their second season, the team is excited to continue working together and competing. The program is intended to be a long-term initiative with old students becoming mentors for newer students.



Students and mentors of the PISCES-RISE Robotics team regularly compete in Vex IQ robotics competitions.

HI-SEARCH International Robotics Competition

PISCES together with a major heavy equipment manufacturer is planning an international robotic mining competition for university teams based on NASA's popular Robotic Mining Competition. Called HI-SEARCH (Hawaii International Space Exploration And Robotics Challenge), the event is slated for Summer 2020 and will be an annual competition for teams from all over the world, including Hawaii. The event will be hosted at a lunar analog site located at NELHA's Hawaii Ocean Science Technology (HOST) Park in Kailua-Kona.

The inaugural competition in 2020 will host up to 21 teams with 200 to 300 people expected to attend. PISCES is seeking corporate sponsorships and local business support for the competition and anticipates the event will bring \$500,000 in revenue to the state.

In addition to economic benefits, HI-SEARCH will highlight Hawaii as a leading state for college robotics and as a world-class location for planetary analog site testing. As a public event, the competition will also give local youth an opportunity to engage and be inspired by robotics, programming and space exploration. HI-SEARCH will also diversify Hawaii's attractions as a tourist destination, and showcase the local students who excel in building, programming and competing with robots.



CORE OBJECTIVES

APPLIED RESEARCH



Technologies for Earth & Space

PISCES conducts projects in Applied Research to develop innovative technologies that can benefit future space missions while spawning new industries here on Earth—especially in Hawaii. Through partnerships with academic, public and private organizations, these research projects are a continual source of funding from state and federal entities that benefit Hawaii's economy. Funding sources include the Small Business Innovation & Research (SBIR) program, NASA's PSTAR program, NASA's NIAC program, NASA's Broad Agency Announcements (BAA) and others.

From its inception, PISCES has been involved in analog field testing with NASA and other international partners

to conduct field tests for planetary exploration technologies. Hawaii is home to among the best analog field sites for Lunar/Mars testing in the world. During the last four years, PISCES has been directly involved in the development of construction- and manufacturing-grade materials made of Hawaiian basalt. There is a growing interest in the space community to understand the chemical properties of basalt for ISRU, and the effects these variations have on sintering.

PISCES expects interest and demand to grow for both planetary analog test sites in Hawaii and basalt research data as NASA continues the early stages of planning its lunar return program, Artemis.

Planetary Analog Sites

During the Apollo era, astronauts tested their field equipment at Apollo Valley on Hawaii Island. Today, NASA and other international agencies consider Hawaii a prime location to continue testing robotics, spacecraft instruments and ISRU equipment.

Since founding, PISCES has sought out and catalogued various planetary analog test sites on Hawaii Island. The island is home to dozens of world-class moon and Mars analog field sites that can support space exploration missions through preflight testing. Hawaii's basalt not only resembles lunar and Martian regolith physically, but also bares a striking chemical similarity as confirmed by PISCES' research.

Serving as a coordinator and guide, PISCES works to ensure that these sites are used in an environmentally and culturally sensitive manner. The sites are spread across the barren volcanic lava fields of Hawaii Island and include high altitude



NELHA's Hawaii Ocean Science & Technology Park in Kailua-Kona offers a high-fidelity lunar analog testing site.

valleys, lava flows and lava tubes. The latest planetary analog site identified in FY19 is located at NELHA's Hawaii Ocean Science & Technology Park in Kailua-Kona. The site will host the 2020 HI-SEARCH international robotics challenge and has raised interest with teams at NASA who are keen to find locations suitable to prepare for the Artemis Program's upcoming lunar missions. PISCES anticipates collaborating with NASA during these tests and participating in various grant proposals to fund them.

He'e Manu Unmanned Aerial Vehicle



An intern configures the He'e Manu UAV.

Under a grant from the County of Hawaii's Department of Research & Development, PISCES purchased a large unmanned aerial vehicle (UAV) in FY18 for a fire ant eradication

project in partnership with the Hawaii Ant Lab. In FY19, PISCES completed the grant project, demonstrating the UAV's capability to spray for fire ants up to 100 feet. The prototype model pumped the pesticide from the ground using a tethered system with ¼" tubing and a high-pressure pump. This design made it possible to spray throughout the duration of the UAV's flight time without landing for refills. PISCES is improving upon this design in FY20 with support from the Akamai Workforce Initiative's internship program, developing an automated tension reel that will feed and remove slack in the tether line during flight.

APPLIED RESEARCH



Above: PISCES Geology and Materials Science Technician Kyla Edison and Intern Kye Harford sift raw basalt fines from a local quarry before pouring them into a mold for sintering.

Basalt Research for Earth & Space Construction

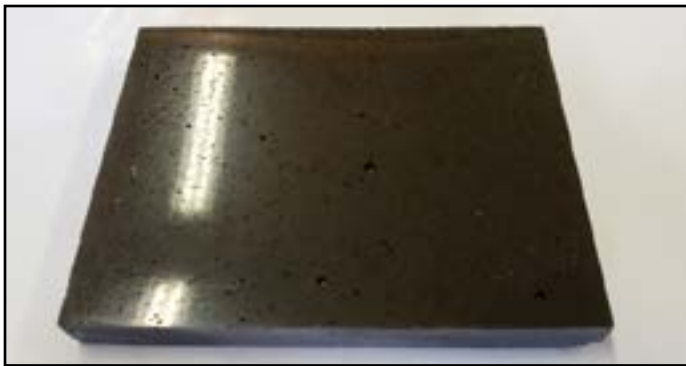
In 2017, PISCES collected basalt samples from various commercial quarries across Hawaii Island to research their effectiveness as a sintering material for construction materials on Earth and in space. (Sintering is a process where fine-grained, free-floating particles are placed in molds and heated to a high temperature until the particles fuse into a consolidated material.)

These samples—which varied from coarse to fine-grained aggregate—were characterized based on their location and origin, chemical composition and mineral abundance. Analyzing each sample, PISCES began compiling a catalog of the most effective basalt compositions that yield a durable construction material

without additives. PISCES completed this comprehensive catalog in FY19. It can serve as a resource for future ISRU research. In space, this could apply to the construction of launch and landing pads, shelters and berms on the moon or Mars. On Earth, these materials could be used for tiles, sidewalk, foundation, countertop, aesthetics and more.

Research & Lab Work

During the last two years, PISCES has found that the composition of starting material plays a significant role in its sinterability. Even the slightest variation in chemical and mineral composition will affect the quality of a resulting product.



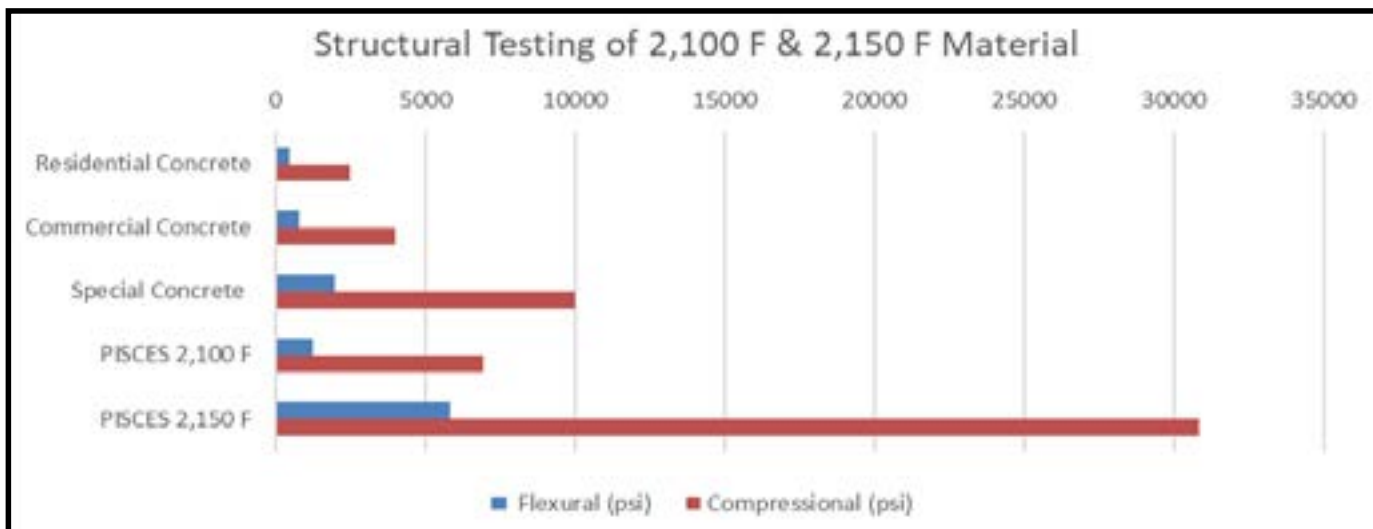
Above: Tiles of sintered basalt (left is polished, right is unpolished).

PISCES tested various samples of Hawaii basalt using energy dispersive x-ray fluorescence (EDXRF)—a device that uses x-rays to analyze matter—to determine their chemical makeup. Next, the samples were studied using x-ray diffraction (XRD) to assess their mineral content. Mineral composition can affect sinterability because not all crystals have the same melting point. (For example, the mineral olivine has a melting temperature of 3,450 °F. At sintering temperature, olivine does not melt, thus leaving voids in the finished product that can compromise its strength.) The aggregate samples were then sieved or crushed into a homogenous grain size before being placed into a mold. The samples were heated at two different thermal profiles: 2,100 °F and 2,150 °F.

Manufacturing

The first generation of sintered materials were tested for flexural and compression strength. The 2,100 °F material was three times stronger than residential concrete. The 2,150 °F material resulted in a material three times stronger than specialty concrete.

PISCES is now producing consistent sintered materials at both temperatures, creating textured and polished tiles. The next step is to have these latest products tested to determine their durability including flexural and compressional analysis, slip, porosity and impact testing. These tests will help validate the structural integrity and potential uses for the material and may lead to large-scale manufacturing.



Structural test results of 2,100 °F & 2,150 °F sintered basalt products compared with different concretes.

FINANCIAL REPORT

Overview of FY19 State of Hawaii Funding

FY19 Budget Ops Request	\$550k
FY19 Ops Funds Appropriated	\$550k
FY19 Ops Funds Allocated	\$517k

Source of State Funds for Operations in FY19

Description	PISCES General Ops.	Basalt Feasibility Study	Total State Funds
FY19 Funds Allocated	\$517k	-	\$517k
FY18 State Funds Carried into FY19	\$239.5k	\$84.7k	\$324.2k

Operating Costs in FY19

Description	PISCES General Ops		Basalt Feasibility Study	Total Operating Costs in FY19
Cost Category	Amount	% of Total	Amount	Amount
Labor	\$382.8k	77.6%	\$15.5k	\$398.3k
Facilities	\$50.6k	10.3%	-	\$50.6k
Consultant	\$2k	0.4%	\$69.2k	\$71.2k
Other	\$57.6k	11.7%	-	\$57.6k
Total Costs	\$493k	100%	\$84.7k	\$577.8k

STAFF

Rodrigo Romo
Program Manager



Rodrigo Romo was appointed Program Manager by the Board of Directors in May 2016. He has 25 years of experience in project management for multidisciplinary projects involving biological/technical systems, power plant operation, research & development, and space exploration focused on robotics and in-situ resource utilization (ISRU).

Polly Roth
Administrator



Polly Roth serves the primary role in accounting, human resources, finances and correspondence with DBEDT as well the Research Corporation of the University of Hawaii. She specializes in non-profit administration and accounting and has worked in the Astronomy industry in Hawaii for more than 20 years.

Christian Andersen
Ops. Manager



As Operations Manager, Christian Andersen oversees PISCES' applied research initiatives and has worked on various projects transitioning aerospace technology to terrestrial applications through analog field testing. He has successfully managed and executed local planning and deployment for several analog field tests with NASA and the CSA.

Kyla Edison
Geology Technician



A former PISCES intern, Kyla Edison is a geologist and materials science technician researching Hawaii's volcanic basalt and its uses as an agent in ISRU construction for space settlement and terrestrial applications. With a background in geology and planetary science, she is also active in community outreach events and activities with local students.

Chris Yoakum
PIO/Outreach



Chris Yoakum is the Public Information Officer and Outreach Coordinator at PISCES. He is responsible for publicizing PISCES' projects through digital media and print publications, managing the agency's social media accounts and other public communications. He also coordinates all outreach and education activities including the STARS Program.

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