

# **PISCES: An International Incubator For Entrepreneurship in Space Exploration and Settlement**

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## **ABSTRACT**

The Pacific International Space Center for Exploration Systems, PISCES, is the world's only center for research and education in science and technology for sustained human presence on the Moon and beyond. When fully developed, PISCES will feature a simulated lunar outpost on the lunar-like volcanic terrain of the Big Island of Hawai'i. Research will focus on the production of energy, food, materials and oxygen for inhabitants of such a settlement, along with its design, operation and governance. Built upon partnerships between industry, academia and government, PISCES will incubate new ideas to enable space exploration and settlement. PISCES' international focus will encourage participation from space agencies around the world. Emphasis on entrepreneurship among participants will ensure involvement by the private sector in the coming expansion of the world's economy into outer space. Situated at the center of the Pacific Rim, encircled by many of the world's space-faring nations, PISCES will enable large and small companies to work with international experts on problems related to living on another planet. It will engender cross-fertilization from university faculty and students *and* government scientists and engineers. In addition to technical areas of concentration, PISCES will stress issues associated with operating a business on the Moon.

## **INTRODUCTION**

When humankind next returns to the Moon, it will do so to *stay*. The technological, cultural and educational consequences of this new reality has led to the creation of a multi-disciplinary Center designed to facilitate this return by (1) providing technological support through lunar analog testing sites, (2) research support through the conduct of cutting edge scientific research into the components that will be required for the venture, (3) entrepreneur support for those smaller companies who seek to capitalize on large scale government and corporate innovations, (4) cultural support by acting as a forum for international discourse among the many space-faring nations of the world, and (5) educational support by articulating links between space-related science and the general public.

We introduce the Pacific International Space Center for Exploration Systems (PISCES-see <http://PISCES.hilo.hawaii.edu>) to the international space community. In its second year of operation, PISCES conducts activities in each of the five areas of support listed above. Highlighted by an impressive list of initial accomplishments and an ambitious, but carefully crafted, ten-year Strategic Plan, PISCES invites participation and partnerships around the world.

## **HISTORY AND BACKGROUND**

PISCES was founded as a research and education Center at the University of Hawai'i at Hilo (UHH) in the Fall of 2007. It is currently administratively housed within the Department of Physics and Astronomy (see <http://astro.uhh.hawaii.edu>) and, as such, is a part of the UHH College of Arts and Sciences. UHH (see <http://www.uhh.hawaii.edu>) is a small, liberal arts unit of the ten-campus University of Hawai'i system, with majors in 34 undergraduate subjects and selected masters and doctoral programs. Approximately 3850 students study in a unique physical and cultural environment. The development of PISCES is the latest in a period of rapid university expansion, which has seen the establishment of a new College of Business, School of Pharmacy, and *Ka Haka 'Ula O Ke'elikōlani*, the world's first College devoted to an indigenous language: Hawaiian. The institution is characterized by strong programs in areas which take advantage of Hawai'i's unique natural resources, including Marine Sciences,

Geology, and Astronomy. It is particularly noted for its career development programs for native Hawaiian and Pacific Islanders with potential interest in the science professions.

PISCES was initially funded by a \$400,000 appropriation from the Hawai'i State Legislature to the state's Department of Business, Economic Development and Tourism (DBEDT) as a part of the establishment of an Office of Aerospace Industries. From the beginning, then, PISCES was seen as an economic engine which would result in jobs and industry for the state of Hawai'i. It places emphasis on programs whose important contribution to space exploration and settlement is matched by positive impact on the local and state economies, on opportunities for UHH students, and on workforce development; particularly for underrepresented minority populations in the science, technology, engineering and mathematics (STEM) professions.

Among PISCES' first priorities was the demonstration that this investment by the State of Hawai'i could be leveraged into significant other investments in the project. Within two months, PISCES was the co-recipient of two cooperative agreements under the U.S. National Aeronautic and Space Administration's (NASA) Innovative Partnerships Program (IPP), representing a more than doubling of the initial investment. While barely in its second year of operation, PISCES has moved beyond its initial funding into a second round of funding based upon its ability to deliver quality services to a variety of international customers.

Alongside efforts to establish fiscal viability, PISCES has produced a 43-page Strategic Plan for the period 2007-2017. The plan contains extensive sections on each of the major topics introduced above and described more fully in what follows.

PISCES is governed by a seventeen member Team consisting of academics from several universities, scientists and business people from several large aerospace corporations, a national Education and Outreach Coordinator, resident operational staff, experts in international aerospace business, and a liaison with the Japanese academic community. It is advised by a Native Hawaiian Cultural Committee which provides insight into ways of conducting business in a culturally sensitive way.

PISCES was conceived as a *university*-based Center. It is committed to developing its tech-

nology and science programs while, at the same time, increasing interest in science among the general public and encouraging interest (specially among underrepresented minority groups) in STEM fields. PISCES actively develops outreach programs and particularly generates space-related curricula both at the elementary/secondary level and the higher education level. We describe below PISCES activities in each of the five categories cited above. We conclude with a description of the PISCES business plan and philosophy and peer briefly into the likely future of PISCES.

## **PISCES SUPPORT PROGRAMS**

### **1 - FIELD TEST OPERATIONAL SUPPORT**

PISCES activities capitalize on the unique terrain and soil (regolith simulant) found on the Big Island of Hawai'i. Examples of extremely fine lunar-like regolith and more weathered, coarser Martian-like environments can be found.



**Two PISCES Field Sites**

The prime research/service program which PISCES offers to the space exploration community is the provision of support services for companies and agencies requiring analog sites for testing *In Situ* Resource Utilization (ISRU), robotics, and other technologies related to a return to the Moon. Customers include the State of Hawai'i (its citizens, institutions and government), NASA, space agencies of other nations, including the Japanese Space Agency (JAXA), the Canadian Space Agency (CSA), industry partners, academic partners, potential philanthropic supporters, and the people of the town of Hilo and the Big Island of Hawai'i.

PISCES is already assembling a growing inventory of equipment necessary for field tests which are added to its existing ability to provide close-by, comfortable lodging and meal services, communications, storage, on-site electrical power,

protective tents and canopies, etc. This equipment, maintained in Hilo in air conditioned protective warehouses, is part of the logistical support which greets potential customers of PISCES analog sites. Residence facilities, including private bathrooms, a dining room and recreational facilities, are located within one mile of the current analog site.



**Lounge at Hale Pohaku Accommodation**

On the University of Hawai'i at Hilo campus, PISCES is able to provide extensive assembly and testing facilities, include a high-bay machine shop, electronic shops, and assembly rooms. These facilities are within easy three-mile access from Hilo International Airport and are in a secure location. The trip to the site is an easy 45 mile drive along good highways.



**Kukahauula Machine Shop**

The use of PISCES as a test/analogy site includes the possibility of assistance from two military air facilities (in addition to the civilian airport) and permits researchers to enjoy all the expected facilities of a mid-sized American town, including hotels, restaurants, movie theaters, shopping malls, etc.

In addition to resident staff and faculty, PISCES acts as a connecting link with an eager population of student workers who combine enthusiasm with expertise. PISCES constructs each test and demonstration according to the needs of its customers. It arranges for transportation and

logistics, obtains necessary permits, acts as liaison between customers and the local business and regulatory community, and provides counsel to assure that a productive test/demonstration is conducted in a manner which is sensitive to local cultural and environmental concerns. A successful PISCES test/demonstration is one where the involved scientists and engineers are free to carry out their work with a minimum of concern about external matters.

In 2008, PISCES will conduct two major test/demonstrations, each with multiple parts. First, it will engage in a test of NASA's Regolith and Environment Science & Oxygen and Lunar Volatile Extraction (RESOLVE) program in collaboration with Kennedy Space Center, Johnson Space Center, Canada's Northern Center for Advanced Technology (NORCAT), and Carnegie-Mellon University.



**SCARAB Rover Used in RESOLVE**

A second test, of the Tweel™ Integrated Tire and Wheel device developed by Michelin Tire, the Jet Propulsion Laboratory and Carnegie-Mellon, will take place during the same period of time.



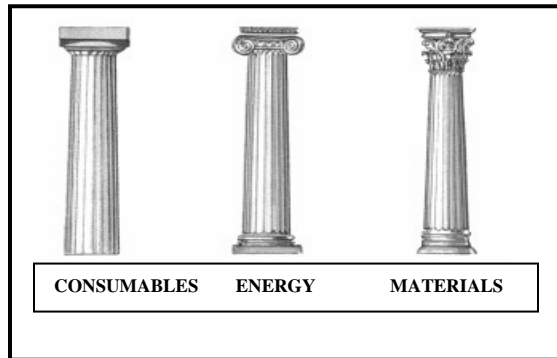
**Tweel™**

**2 – RESEARCH SUPPORT**

In addition to providing support for research conducted by its customers, PISCES is a university-based scientific operation that conducts its own research in collaboration with UHH

partners including Colorado School of Mines (CSM) and the University of Houston (UHouston).

The central theme of the research at PISCES is the concept of “Pillars of Sustainability” for humans in a lunar settlement. These three pillars: *consumables* (food, air production from regolith, environmental control and life support), *energy* (collection of solar energy on the lunar surface, chemical fuel and propellant production from lunar regolith, and bio-fuel production) and *materials* (production of construction materials and manufacturing materials from lunar regolith) are collectively described as the new field of Lunar Human Ecology (LHE), which PISCES hopes to develop as a node of NASA's newly announced NASA Lunar Science Institute (NLSI) to which it has applied for a multi-year grant.



**Pillars of Human Lunar Ecology**

As coordinator of the project, PISCES will coordinate activities at multiple locations, including the UHH College of Agriculture, Forest, and Natural Resources Management (CAFNRM), the Center for Advanced Materials at UHouston, the Center for Space Resources (CRS) at the Colorado School of Mines, the Advanced Coatings and Surface Engineering Laboratory also at CSM, and private industry.

Additional current PISCES research efforts include collaboration with the Information and Computer Sciences department and the Telehealth Research Institute (TRI) at the University of Hawai'i at Manoa (UHM) in “A *prototype virtual/augmented reality system for planning, training and execution.*” This proposal, submitted to the NASA Applied Information Systems Research Division envisions the use of mixed and virtual reality as a training tool for extra-vehicular sorties by astronauts both in transit and on the Moon.



**VR hardware being training application at the UH Telemedicine Institute.**

### **3 – SUPPORT FOR ENTREPRENEURS**

Entrepreneurial small businesses are important PISCES partners. While we work closely with NASA and other space agencies from around the world, along with the large aerospace companies with which they typically contract to support their space missions, we recognize that the majority of innovations and entrepreneurial activities come out of small companies. These are the companies that are most interested in long-range research because they are growing and not as focused on short-term bottom-line return to stockholders as the larger companies. They are also the most likely to be interested in terrestrial spin-offs of space research since that is an area requiring a strong entrepreneurial perspective and a creative approach to applied research. Terrestrial spin-offs are also of major interest to PISCES since we are chartered in part as an economic development engine for the State of Hawai'i in general and the Big Island of Hawai'i in particular.

However, it is also true that small entrepreneurial companies often have difficulty raising capital for space ventures that won't yield a profit for many years. For this reason, terrestrial spin-offs that have more near-term applications are even more important to companies such as these because the resulting products and services are more likely to keep the company in business until the space applications become a reality.

Recognizing this situation and the benefits accruing to the economy from innovative research by these entrepreneurial companies, the U.S. government many years ago established the Small Business Innovative Research (SBIR) program and its companion, the Small Technology Transfer Research (STTR) program. Under these programs, each federal agency that does research and

development is required to dedicate a certain percentage of its R&D budget to SBIR and STTR programs within that agency. NASA's SBIR and STTR programs have resulted in thousands of inventions that have found space and terrestrial applications. See <http://ipp.nasa.gov> and <http://sbir.gsfc.nasa.gov/SBIR/successvideo.html> for more information on these programs.

PISCES provides support for entrepreneurs by joining with them to apply for SBIR/STTR grants to conduct research related to sustaining life on the Moon and beyond. These research programs are carried out in laboratories at the participating companies and also at UH-Hilo and the PISCES academic partners at UH-Manoa, the University of Houston and the Colorado School of Mines. In these programs, testing and demonstrations can be conducted at the PISCES field sites and eventually at the PISCES Analog Outpost.

In addition to support in the form of facilities, PISCES provides entrepreneurs with assistance in developing proposals, access to faculty and student expertise, connections with other PISCES partners including NASA, favorable intellectual property arrangements and confidentiality agreements.

PISCES makes it a priority to publicize partner involvement, both locally and nationally, through the many media connections that we have developed. For example, we have had numerous articles in the Hilo and Honolulu newspapers and on local TV stations, and when we won two IPP grants the news appeared in over 160 outlets nationwide. Companies that do business with us benefit from that exposure. Some entrepreneurial companies with which we are working and that will be giving presentations at the upcoming JUSTSAP/PISCES Symposium include Paragon Space Development, Odyssey Moon and Astrobotics.

### **4 – SUPPORT FOR INTERNATIONAL DIALOG**

PISCES' focus on international dialog is a natural extension of its evolution from an existing international forum for discourse between scientists: the Japan-United States Science Technology and Space Applications Program (JUSTSAP-see <http://justsap.org>). In its seventeenth year of existence, JUSTSAP meets annually in Hawai'i, midway between its two sponsoring countries, to encourage international scientific cooperation.

The first of JUSTSAP's projects to attain independent status, PISCES will soon be followed by a project in Energy Transmission and projects associated with the commercialization of space.

The current PISCES test/demonstration projects being carried out for NASA contain significant international involvement, with teams coming from Canada, Japan and Germany taking part in the program. An estimated 75 people from at least four countries will be involved. Located in the center of the Pacific Ocean, PISCES in Hawai'i is ringed by the majority of the space-faring nations of the Earth: The United States, Canada, Japan, China, and Russia.

PISCES participation in the 59<sup>th</sup> International Astronautical Congress represents its efforts to expand international interactions to include Europe, with future plans for outreach to the Indian Space Agency under consideration.

An important part of PISCES ethos includes its commitment to conduct its activities in a manner sensitive to local cultural and environmental concerns in areas of its operation. In common with several locations whose geographic features make them desirable for astronomy or for lunar analog tests, Hawai'i contains a number of populations which are sensitive to the cultural effects of scientific exploitation. One of the important contributions which PISCES makes to the conduct of test/demonstrations is its reputation for sensitivity to local concerns and its ability to bring people with diverse interests together to the benefit of all concerned. PISCES has successfully avoided the political pitfalls which often accompany scientific undertakings that do not have this level of sensitivity.

PISCES is currently engaged in a collaborative effort with the 'Imiloa Astronomy Center of UHH in the development of informal education programs connecting historic Polynesian wayfaring with modern spacefaring. Entitled "*From Oceania to Space: Inspiring the Next Generation of Voyagers,*" this project will draw analogies between the Polynesian voyages of discovery and colonization of the thirteenth century with today's voyages of discovery and colonization of the Moon and Mars. Aimed at providing families with an appreciation of the value of space exploration as an extension of their cultural identity, this project will serve as a model for other, similar efforts.



## **5 – SUPPORT FOR EDUCATION AND OUTREACH**

PISCES supports Education and Public Outreach (EPO) activities both as components of all of its projects and as specific goals of its EPO projects.

An example of the former is the EPO component of the November 2008 test/demonstrations described above. Arranged through PISCES, NASA officials will spend an entire morning at four different local schools talking with students, describing NASA projects involving robots and ISRU and explaining NASA's Constellation Program. In addition, at the end of the test/demonstration, the equipment will be transported to the 'Imiloa Astronomy Center on the UHH campus for a public demonstration of the equipment that will include opportunities for youngsters and their parents actually to operate the vehicles. 'Imiloa, an interpretive museum/planetarium that seeks to make connections between science and Polynesian culture, is a partner with PISCES in the development of projects described as "informal education" because they exist outside the classroom to enhance public interest and understanding.



**'Imiloa Astronomy Center**

PISCES is working with UHH and the national SpaceClass™ (see <http://www.spaceclass.org/>) program to produce space exploration-related instructional modules for use in the public schools. Students recruited from UHH's Keaholoa STEM Program, which increases enrollment, graduation and support rates of Native Hawaiian Students at UHH, will work in collaboration with PISCES will be trained to give talks at local schools about the relevance of space science to their lives.

At the University level, PISCES is developing a variety of individual space-related academic courses toward the ultimate goal of establishing a Space Studies certificate or degree.

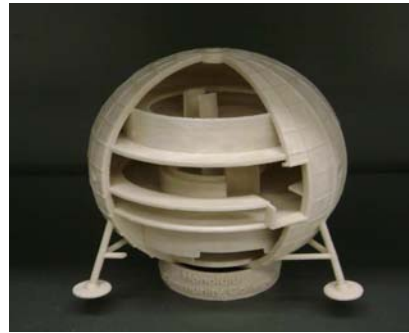


**UHH Physics and Astronomy Students**

Notable in the project is its multi-disciplinary nature. The program is a Space *Studies* program; not a Space *Science* program. In addition to expected courses from the Physics & Astronomy department in Space Flight, Introduction to Computing with Robots and Electronics, it features courses in Kinesiology (Human Physiology and Spaceflight), Astrobiology, Political Science (Political Science and Futuristics), Philosophy (Cosmology: Science and the Human Prospect), and even English (Science Fiction and Space Flight). Faculty members from multiple campuses in the UH system are working together toward the development of the first system-wide academic degree program in the 80 year history of the institution.

For the second year, PISCES is sponsoring a national Student Design Competition in which student/faculty teams from around the United States submit their concepts for solving any of a variety of technical problems which must be overcome before humans can return to the Moon to stay. Wide latitude is given to teams in their selection of issues, resulting in submissions varying from highly technical ISRU projects to broader operations management analyses. Annually, two or three finalist teams are selected

by an impartial panel of judges and are invited to attend the annual JUSTSAP/PISCES Conference as the guests of PISCES, where they compete to become the final winner. In its first year of operation, the panel invited finalists from the Colorado School of Mines, the University of Colorado, and Honolulu Community College (the eventual winner with a lunar habitat design).



**Honolulu CC Habitat Design**

In 2008, teams from the Massachusetts Institute of Technology and Virginia Polytechnic Institute will make presentations at the Conference at the Hilton Waikoloa Hotel in November, with the winner announced at the end of the Conference.

## **BUSINESS PLAN**

### **PISCES BUSINESS PHILOSOPHY**

PISCES will adopt a seamless research-to-deployment approach, bridging the so-called “technology valley of death” that results when research and applications take place in organizations separated both physically and culturally. Specific sales strategies include:

- a) Promoting the unique characteristics of the Big Island for lunar and Martian research and simulation.
- b) Emphasizing dual-use technology development to attract non-aerospace companies.
- c) Enlisting faculty members with expertise in required disciplines.
- d) Partnering with institutions offering complementary expertise.

- e) Making heavy use of the PISCES website to reach broader audiences.
- f) Developing promotional materials such as brochures, videos, displays, etc.
- g) Aggressively pursuing news coverage of PISCES activities.
- h) Hosting topical seminars, workshop and other public events.
- i) Expanding Education and Public Outreach activities.

The PISCES business model is that of an industry-university-government partnership. This model has already been employed with the development of test demonstration arrangements with NASA through our IPP cooperative agreements and includes participants from Canada, Japan and Germany. To the greatest extent possible, in these activities PISCES depends on scientist-scientist contacts.

In centers of this type, a formal industrial partnership mechanism is put in place through a legal agreement, whereby the company pays an annual membership fee in exchange for access to the Center's faculty and student expertise. We envision an industry membership agreement with fees ranging from \$10K/year to \$30K/year depending upon company size. Revenues are expected to rise from ~\$500K in the first year to ~\$7 million in year ten, with expenditures keeping pace.

### **FACILITIES PLAN**

When completed, PISCES will be a physical Center, as well as a center of ideas. PISCES will consist of three components: its test sites on the slopes of the Big Island, a campus base facility, and a mid-level facility built at approximately 6500 foot altitude near the road which traverses the saddle between Mauna Loa and Mauna Kea.

#### **Base Facility**

PISCES will construct a base facility on the university campus. At an estimated cost of \$12 million, the facility will house PISCES administrative offices, working space for staff, students and visiting faculty, classrooms, laboratories, a conference room, two instrument shops and a high-bay area with machine shop and storage

space. UHH maintains a Technology Park with research facilities including astronomy centers from more than five countries, a Department of Forest research center, and an agricultural research center. Ample space suitable for PISCES remains in the Park.

#### **Analog Outpost**

The future centerpiece of PISCES will be a full-scale, technically valid, analog simulation of a lunar outpost. It will consist of a number of modules linked together to provide support to human crews that will perform research, operations and housekeeping tasks. The full facility will provide habitats, power, life support systems, communications, surface activity support, lunar ISRU systems and landing support systems. In addition to serving as a developmental prototype of a lunar outpost where full-scale simulations can be performed, it will enable continued research into the various sub-fields of LHE. It will also serve as a public center where interested individuals can watch PISCES in action. Estimated cost is \$8.75 million.

#### **Field Site(s)**

The third component of the PISCES facilities plan is a virtual facility in the sense that no permanent structures are anticipated at the various sites identified as appropriate for different analog test/demonstrations. After careful vetting to assure that both environmental and cultural concerns are addressed, sites will be selected as required by PISCES customers. An inventory of portable service equipment (shelters, electric generators, food service equipment, etc.) is assembled for use in the field as appropriate and collectively represent this third 'facility.'

### **PISCES – THE FUTURE**

In the relatively short time during which PISCES has been in existence, it appears to have made a considerable name for itself in the aerospace community. Arguably, PISCES meets a genuine need of the community and has come into existence at exactly the right time. It combines scientific/technical competence with a unique geographical location. PISCES activities benefit from its location on a university campus which provides both faculty members and students sharing the passion for a return to space. The

addition of EPO components, an appreciation of the importance of international dialog and a cultural sensitivity complete the picture. As an entrepreneurial enterprise, PISCES welcomes collaborations with academicians, small companies, larger corporations and government agencies from around the world. The saying that “the sky’s the limit” might have been specially written just for PISCES.