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Pacific International Space Center for Exploration Systems

Lunar Human Ecology: A New Scientific Discipline

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2009 Conference, Ames Research Center

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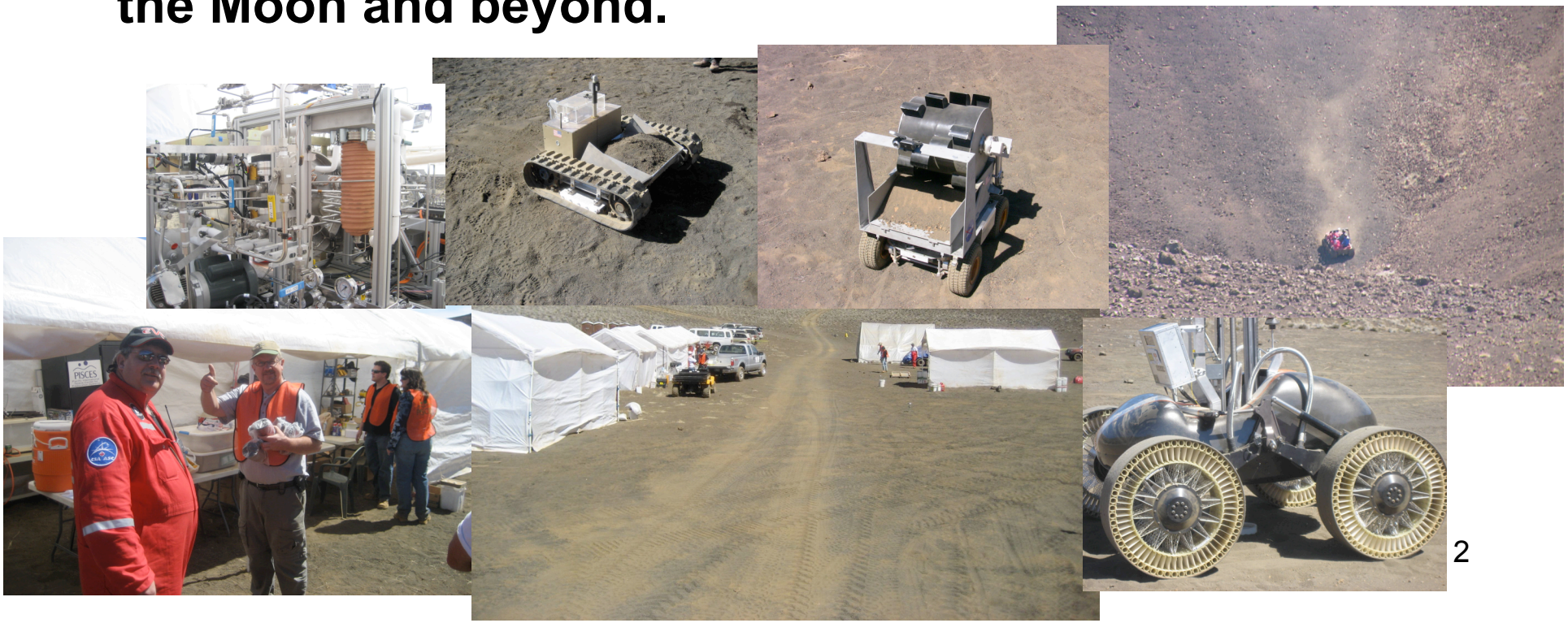
Introduction

PISCES and Science "On The Moon"

- **PISCES, established at the University of Hawai`i at Hilo in 2007 and funded by the State of Hawai`i and international lunar analog testing projects, has been engaged in a highly successful program of testing and demonstration of new technologies to sustain life on the Moon and beyond.**



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Introduction

PISCES and Lunar Human Ecology

- **Lunar Human Ecology is envisioned as a new science that can unify the planned research and development efforts at PISCES.**
- **This paper is not a report of results but a presentation of the concepts underlying Lunar Human Ecology and possible research avenues to pursue in a program of science "on the Moon" designed to lay a scientific foundation for permanent lunar settlement.**
- **We invite your comments: http://pisces@hilo.hawaii.edu**
- **And participation!**

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Vision

Self-Sustained Human Presence

- **Permanent lunar settlements relying minimally on re-supply from Earth.**
- **We need an approach that is broader than terrestrial ecology, which is a study of how living systems adapt and interact with an environment that is largely provided naturally on Earth. On the Moon, that environment must be created.**
- **We need to develop more than closed-loop life support systems of the kind used on ISS. Lunar settlement systems will be open to Energy and Materials.**
- **We need to understand basic scientific underpinnings of a self-sustaining system in order to understand the priorities that should be given to the technologies that would allow such a vision to be realized.**

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Assumptions

Independent of Current Policy

- **We adopt a vision for lunar settlement that goes well beyond anything visualized in current space programs.**
- **Early development to be undertaken as part of NASA's Constellation program provides a foothold on the Moon.**
- **Working backward from the assumption of a self-sustaining settlement, perhaps of many people, can provide a basis for new scientific thinking as well as identifying future possibilities.**
- **There will be an evolution of capability from a system that requires nearly complete resupply of everything except water and air to one that re-uses much of its wastes and fully utilizes local resources.**

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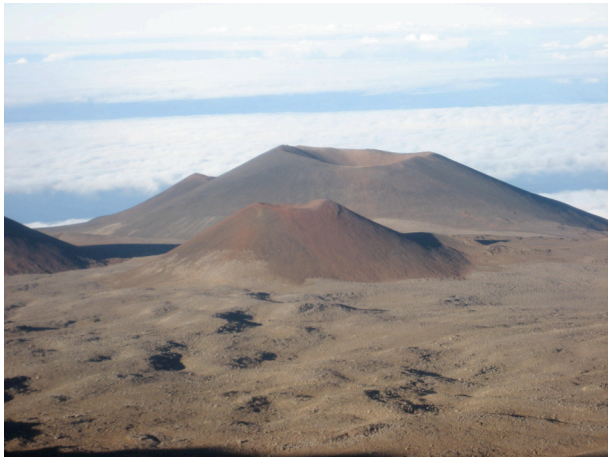
Goals

Dual-Purpose Research

- **To advance our understanding of the Moon in the context of lunar exploration and eventual settlement.**



- **To have an impact on the Island of Hawai`i, which is a good analog for the Moon and is in many ways an isolated eco-system representative of many throughout the Pacific Basin and in other remote parts of the world.**

Lunar Human Ecology Defined

- **A Study of the Interactions Between Humans, Their Systems and the Lunar Environment**
- **A Top-Down Scientific Approach to Sustained Human Presence on the Moon, as Opposed to Applied Engineering and the Development of Specific Technologies**
- **An Integrating Science that Can Help Identify Needed Areas of Research Before We Get Back to the Moon**
- **A Scientific Basis for Making the Best Use of Local Resources to Limit Expensive Imports from Earth After We Get Back to the Moon**
- **The Guiding Principle Underlying Development of the Pacific International Space Center for Exploration Systems (PISCES)**

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Basic Needs

Pillars of Sustainability

- **Consumables**
  - **Oxygen, Water, Plant Nutrients, Food**
- **Energy**
  - **Collection, Storage and Delivery of the Moon's Natural Energy Supply**
- **Materials**
  - **Basic Feedstocks for Construction and Manufacturing**

Some Important Elements

Lunar Environment	Living Systems	Science	Technology
1/6 Earth gravity	Food, air, water	Lunar geology	Life support
High vacuum	Energy	Lunar petrology	ISRU
Charged particles	Plant nutrients	Materials science	Energy
Electrical fields	Pressurized volumes	Extractive processes	Communication
Dust	Human physiology	Vacuum physics	Navigation
Large temp. swings	Waste processing		EVA/Surface Exploration
Raw materials	Communication		Materials and Manufacturing
Solar energy			Habitability systems

Some Key Interactions & Implications

Use ↓ Benefit →	Energy	Materials	Consumables
Energy	• *Capture* • *Storage* • *Transmission*	• Process energy	• Process energy, light, heat • Form, power levels, duty cycle; Recycle wastes
Materials	• Si for PV cells • Solids for substrates, supports	• *Match materials and synthesis techniques to applications* • *Mechanical, chemical, physical properties* • *Interaction with environment*	• Agricultural system construction materials • Thermal insulation • Pressurizable containment, plumbing systems; radiation protection
Consumables	• Source of minor metals, non-metals and oxides • Reagents for chemical energy storage • Utilize byproducts to minimize waste • Biomass as local energy source	• Source of reactants (C, H, S) • Biological concentration of minor or trace elements	• *Isolation from vacuum* • *Exploration for best sources of particular elements* • *Beneficiation techniques* • *Food growing; closed life support systems*

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Objectives

Near-Term

- **Develop mass and energy flow models that describe Lunar Human Ecology and define the most important research problems.**
- **Conduct research on key variables that underlie assumptions in the model.**
- **Validate interactions between multiple subsystems and biological systems.**
- **Study long-term effects of interactions with subsystems that either depend on biological processes (plant growth, biological water treatment), or are affected by biological processes (eg; bio-film formation or biodegradation of materials)**
- **Plan experimental protocols to advance understanding when humans are actually on the Moon again.**

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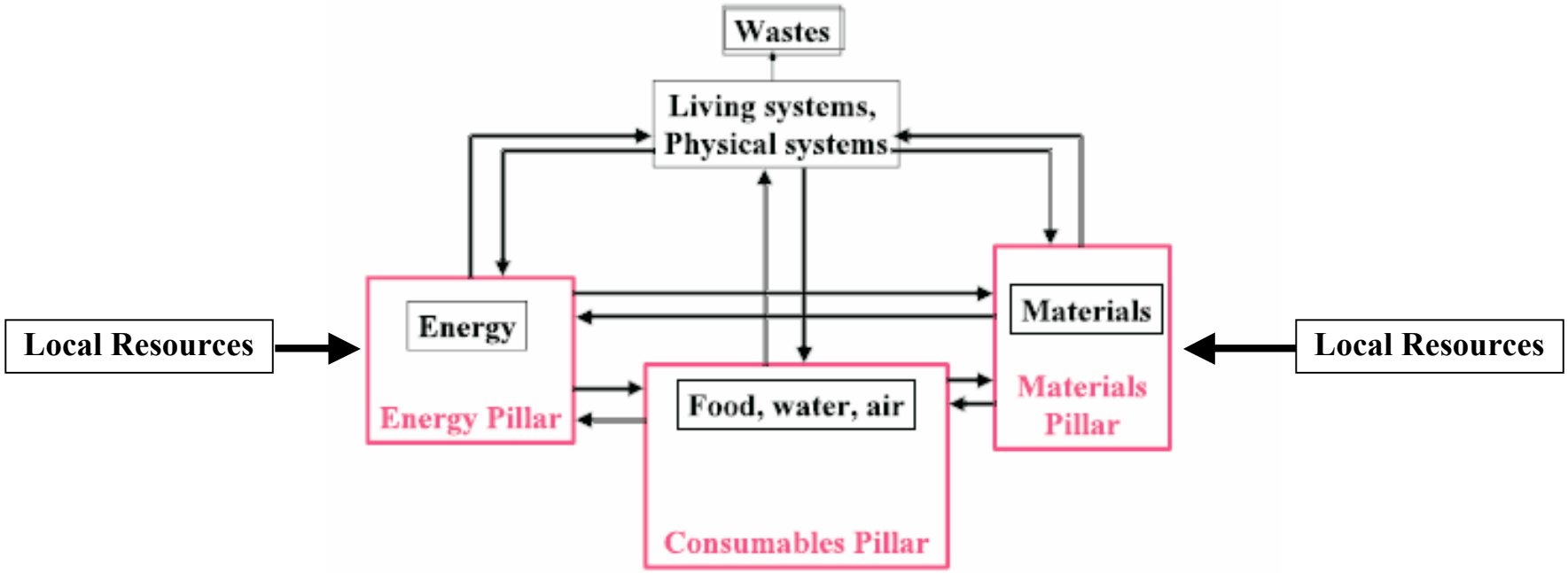
Objectives

Long-Term

- **Establish Lunar Human Ecology as an integrated science unique to the Moon**
- **Create a simulation model for a lunar settlement that includes the interactions between the three Pillars of Sustainability and human occupants.**
- **Provide a much-improved understanding of the natural materials of the Moon and their interactions with reactants brought from Earth or produced on the Moon.**
- **Create relevant test cases that demonstrate the interactions of physical and biological systems with the natural lunar environment**
- **Develop new materials and demonstrate processes made uniquely possible by the lunar environment and understand how lunar resources can be used to make items taken for granted on Earth.**
- **Define experiments important to LHE that can be performed on the Moon by robotic missions or by human explorers at an early lunar outpost.**

Modeling

Energy and Mass Flows



- **Model will allow sensitivity testing to identify the most important interactions for further research.**
- **Model will allow other research objectives to be placed into the context of a functioning lunar settlement.**

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Questions

Consumables

- What are the chemical cycles for specific major elements in the food cycle (C, H, N) throughout a complete plant growth generation (including recycling of biomass wastes)?
- What are the chemical cycles for selected minor elements, particularly potassium and phosphorous, which are critical for plant growth?
- What are the rates associated with the recycling of these elements from plant waste?
- What is the fate of these elements in human consumption?
- What processes can be utilized to speed up any parts of the system that are slow?
- How can local resources best be utilized in a food production system?
- What are the interactions between materials produced from local resources and biological systems?

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Questions

Energy

- **What are the properties of acceptable glasses made from lunar materials to serve as substrates for silicon photovoltaic devices?**
- **How can the micro-crystallinity of silicon in solar cells fabricated by vacuum deposition be controlled so that optimum efficiency can be gained?**
- **How can radiation damage effects be mitigated in lunar fabricated silicon solar cells?**
- **How do the structural/mineralogical properties of lunar materials determine the quality of reflective surfaces that can be produced?**
- **How can we bootstrap solar concentrator manufacture to provide for further materials processing?**

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Questions

Materials

- **How do starting compositions of lunar materials, the processes themselves, and the lunar environment affect the properties of materials prepared using various processes?**
- **How do starting structures, both mineralogic and microscopic, influence properties of the final products such as strength, durability, porosity and permeability, and how might those influences differ between Earth and Moon?**
- **How do the starting structures present on the Moon compare with those on the Earth, particularly in the "Hawaiian Regolith" that PISCES will use as an analog material?**
- **What will be the final microscopic structures produced in the lunar environment and how will they be affected by the lunar environment?**
- **How can processes for turning lunar material into useful processes be adapted to make the best use of lunar conditions, thereby turning potential problems into opportunities?**

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Summary

Lunar Human Ecology

- **Is a unifying science that will guide research to sustain life on the Moon, as opposed to "point design" of individual systems.**
- **The goal is to understand, not to discern the actual developments that are possible, feasible and productive, although that understanding can guide research into specific systems.**
- **The approach is one of asking questions, not specifying requirements, although studies are guided by an understanding of what is needed practically to sustain long term habitation of the Moon.**
- **Lunar Human Ecology will guide the development of PISCES and complement the highly successful testing and demonstration of technologies already underway at our site in Hawai`i.**
- **Dual-purpose spin-offs will contribute to the solution of energy, materials and sustainable agriculture issues in Hawai`i and in similarly remote locations throughout the world.**


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Thank You!
from the PISCES Community
Pacific International Space Center for Exploration Systems (PISCES)
PISCES
Come Join Us at Our
Workshop in Hilo!
November 2-6, 2009
http://pisces.hilo.hawaii.edu