Lunar Planetary Protection Testbeds and Life Support for Mars Exploration

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Long Duration Biological Studies in Lunar Gravity

Two Basic (but different!) Motivations:

- Better understand life on Earth by using reduced gravity as a probe ito study the behavior of living systems
  - For example, determine which genes and signaling pathways are affected when the gravitational signal is altered
- Determine whether biological systems can adapt to the lowered gravity of the Moon over long periods
  - Is there a gravitational threshold?

THIS TALK AND THIS CONFERENCE ARE NOT ABOUT BIOLOGICAL STUDIES (sorry Milou)—BUT LATER WE NEED TO FOCUS ON “INSIDE”

Planetary Protection

Integrated Testbeds

Why do we need them?

- Allows for validating planetary protection approach in real environment (technology & ops)
- Personnel are exposed to normal and off-nominal procedures, allowing for a test of the operational plans for Mars in a high-fidelity setting
- Effects of the functioning of personnel in interactions with the support subsystems and among themselves can be determined
  - Operational environment cannot be adequately simulated in laboratory studies
- *System*-level behavior of crew and subsystems, together, is critical to future mission success

ESA/NASA Workshop (May 2005): Ops Group Recommended Planetary Protection Requirements for Humans on Mars

Assumptions

- The greater capabilities of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- It will be not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars will inevitably be exposed to martian materials. To the maximum extent practicable, these exposures should occur under controlled conditions.
- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.

Overall Policy Requirements (Level 0)

- Planetary protection shall be considered a critical element for the success of human missions to Mars
- Evaluation of planetary protection requirements shall be considered in all human Mars mission subsystems development
- Planetary protection considerations shall be included in human Mars mission planning, training, operations protocols, and mission execution.

Conceptual Approach

- Human missions to Mars shall not affect or otherwise contaminate “special regions” of Mars, nor be contaminated by materials from them
  - Mission cleanliness and containment requirements shall avoid the inadvertent introduction of Earth organisms or organic molecules into these environments, and the inadvertant exposure of human explorers
  - Landing site selection and operational accessibility to scientifically desirable special regions (including prime access to ISRU-important subsurface ice or water) shall be traded against the microbial or organic cleanliness of human-associated (or robotic) systems
- Calculations based on this approach will determine the allowable levels and kinds of contamination allowed for specific aspects of any particular human mission.

Definition of “Special Region”

A Special Region is defined as a region within which terrestrial organisms are likely to propagate,

OR

A region which is interpreted to have a high potential for the existence of extant Martian life forms.

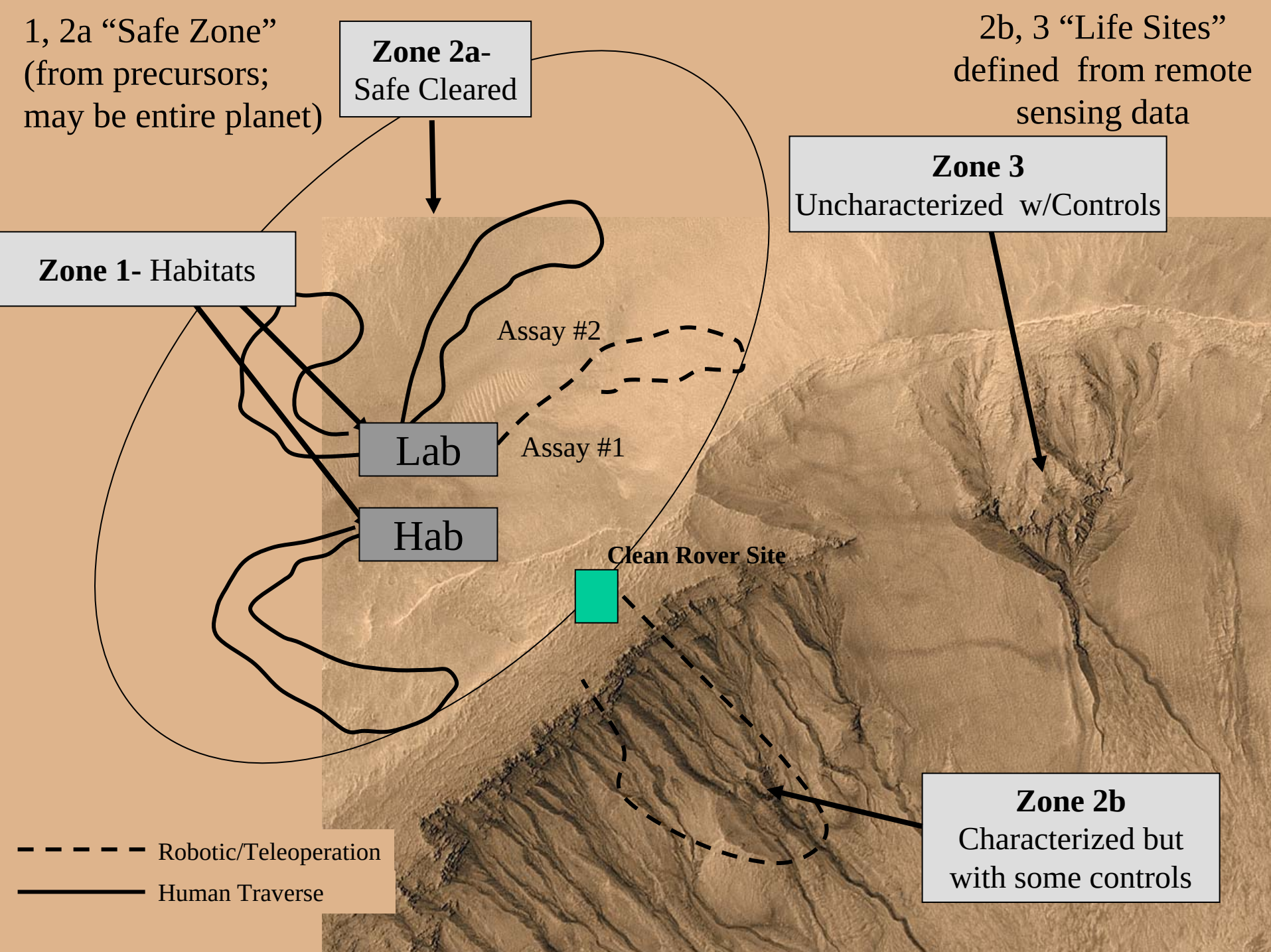
Think liquid water, at a temperature to support life

PP General Issues

1. Planetary protection risks are among the many risks to be identified and evaluated together—then reduced, mitigated, or eliminated when possible to enable mission success.

2. General human factors need to be considered along with planetary protection issues for a human mission to Mars.

3. A crewmember onboard the mission should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.


1, 2a "Safe Zone"
(from precursors;
may be entire planet)
Zone 2a-
Safe Cleared
2b, 3 "Life Sites"
defined from remote
sensing data
Zone 3
Uncharacterized w/Controls
Zone 1- Habitats
Assay #2
Lab
Assay #1
Hab
Clean Rover Site
Zone 2b
Characterized but
with some controls
Robotic/Teleoperation
Human Traverse

Forward Contamination Control

Additional development and design is needed to characterize exploration, sampling, and base activities to assure effective operations and the required level of planetary protection control

- Processes associated with EVA egress/ingress must be characterized and optimized
- An inventory of microbial populations (and organics) carried aboard and potentially released by human-associated spacecraft and suits should be established and maintained in support of both planetary protection and crew-health objectives
- Systems should be provided to allow controlled, aseptic, subsurface sampling operations, so that uncontaminated samples can be returned to the surface, and so that human-associated contaminants are not introduced to the subsurface.

Backward Contamination

[Short loop] Operations of a human mission to a new site shall include isolation of humans from directly contacting martian materials until initial testing (either precursor-mission or on-mission robotic testing) can provide a state-of-the-art verification of the landing site as a “zone of minimum biological risk” (per the NRC recommendation in *Safe on Mars* [1992]).

Exploration, sampling, and base activities should be accomplished in a manner to limit inadvertant exposure to the subsurface or to otherwise-untested areas of Mars

- A means for allowing controlled access to those areas shall be provided.

Backward Contamination (cont.)

A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a martian life-form occurs

- As part of normal crew health monitoring and in support of the assessment of possible quarantine measures, basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes shall be defined, provided, and employed regularly on the mission.
- A quarantine capability and appropriate medical testing shall be provided for the crew upon return to the Earth (Moon or Earth-orbit) and if necessary, implemented in conjunction with a health monitoring and stabilization program.

Backward Contamination (cont.)

[Long Loop] Samples returned by the crew from uncharacterized or otherwise-untested areas of Mars shall be considered as potentially hazardous, and shall not be released from containment unless they are subjected to a sterilizing process, or until a series of tests determines that they do not present a biohazard.

Off-Nominal Events to be Worked/Tested in Appropriate Testbeds

- Crash of cargo or human carrying vehicle, or a subset of spacecraft-carried material (jettison)
- Fire in habitat suppressed by depressurization, or other factors resulting in breach of habitat integrity
- Tear or other failure in EVA system
- Partial failure of ALS system or critical components
- Waste containment/filtering breach
- ISRU recovery contamination event
- Nuclear-power system thermal containment effects/breach
- Other power-system failure (battery leakage, fuel cell degradation/failure, tank explosion…)
- Breach of pressurized rover

Amelioration of Plantary Protection effects involves site identification, documentation of incident, and possible remediation of localized contamination

Advanced Life Support:
Discussion Points

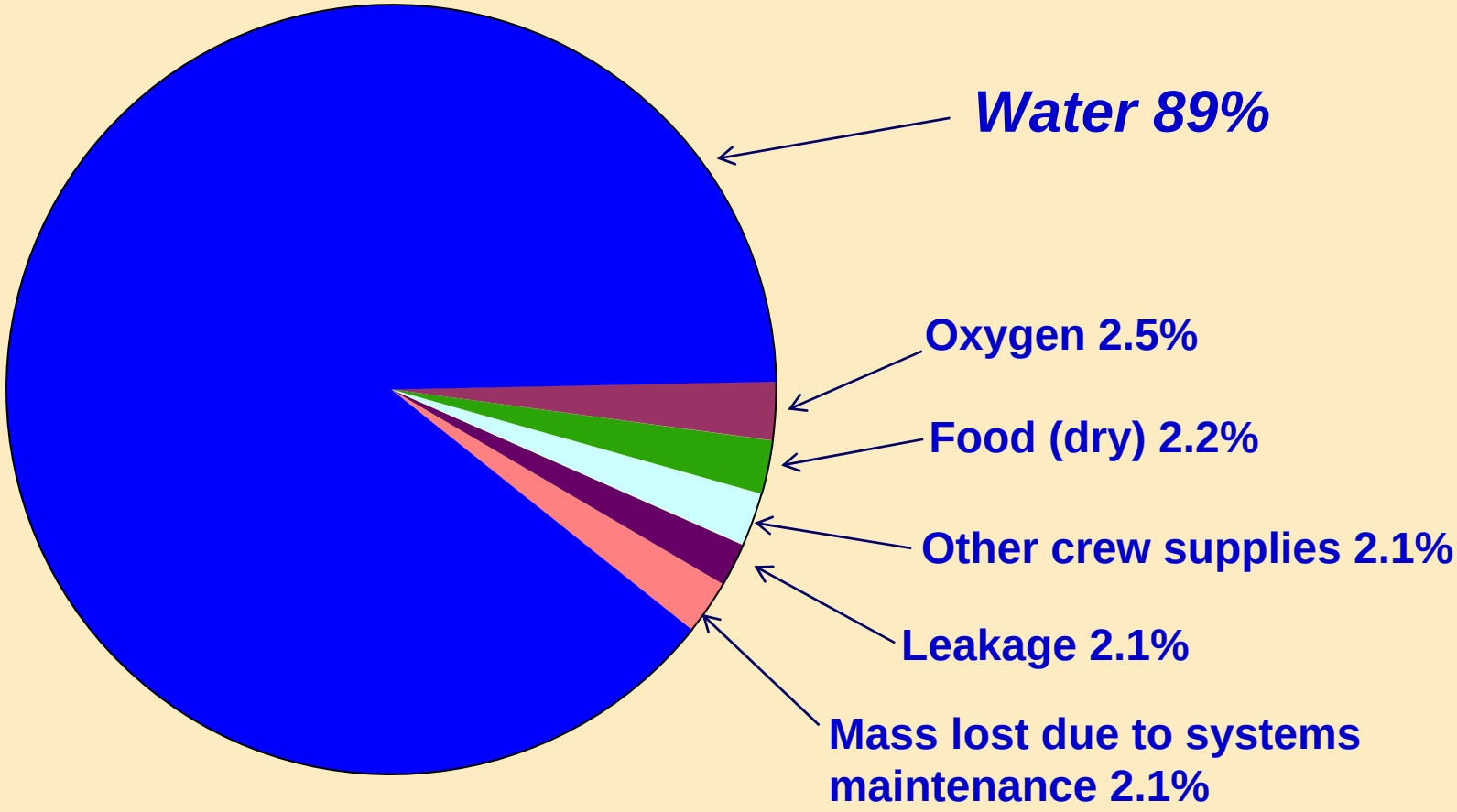
- ALS is an *Enabling* technology for human exploration and development of space
- Long-duration missions dictate regenerative systems — minimize re-supply amounts/cost/ dependency
- Minimize mass, volume, power, thermal requirements (per the minimize-cost point)

and, BTW

- We have failed to progress very far in the ~45 years of human spaceflight

The Problem

Human Requirements Estimate:
Resupply Mass - up to 12,000 kg / person-year



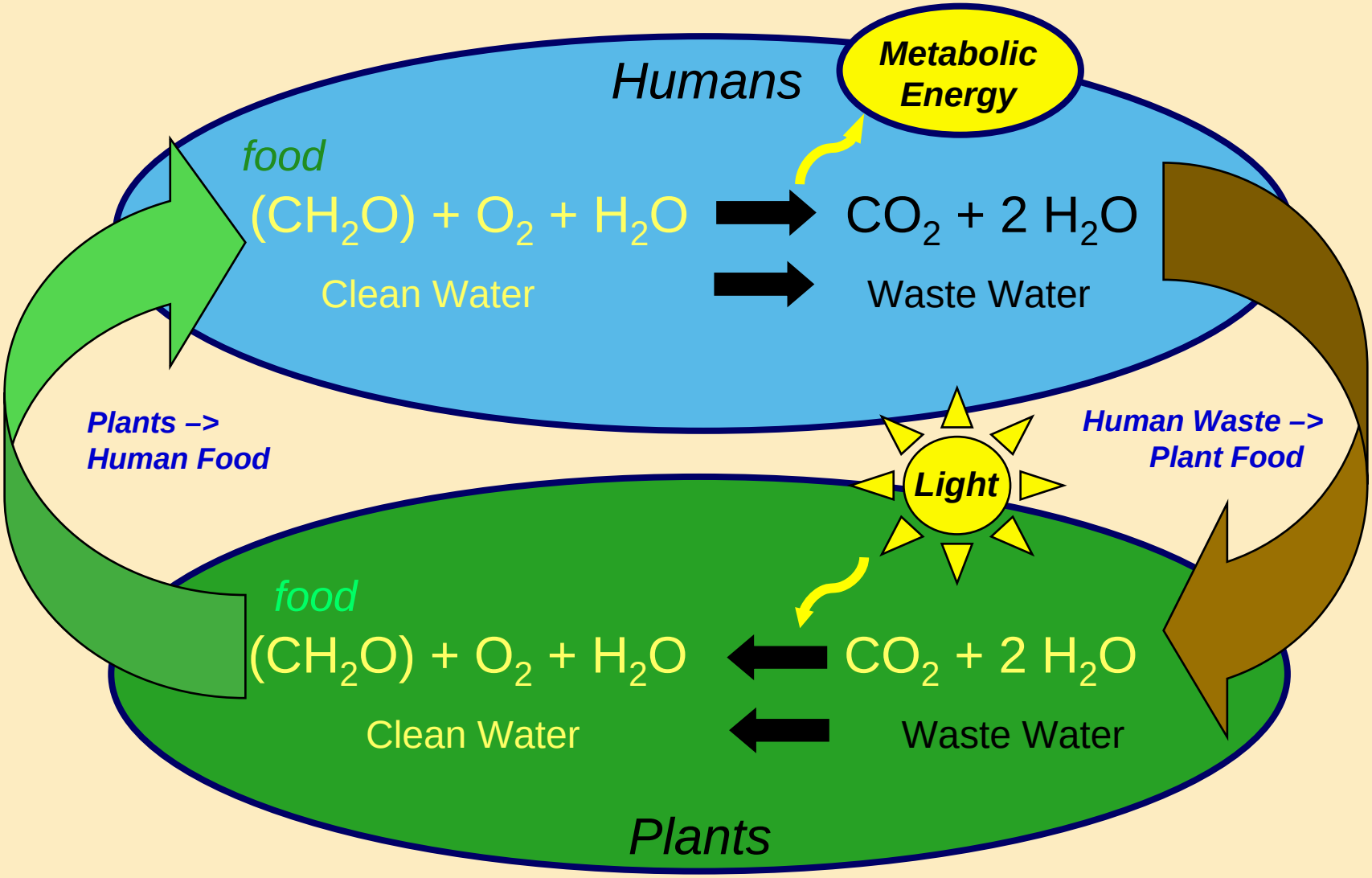
Traditional Life Support System

Some Neglected Features in the Last Slide....

- **Oceans** (not shown), an important, but heavy, way to store water
- **Recycling of the crust by subduction and volcanism** (not shown–mountains are only a hint)
- **Precipitation, runoff, and burial of organics** (mountain snows are a hint, but process not shown)
- **Edible plant growth** (you can eat a goose, but you can't eat a pine tree–at least not those pine trees)
- **Fish** (in space, you don't worry about your goslings getting eaten by a Northern Pike...) or other protein sources
- **Sun** (it is Canada, after all) or any other energy source
- **Humans** (an important LIVING component of our favorite space life support systems....)

The CELSS Concept

Think “ISRRU”



“Thou Shalt Not Live on Bread Alone”

– But it’s a start

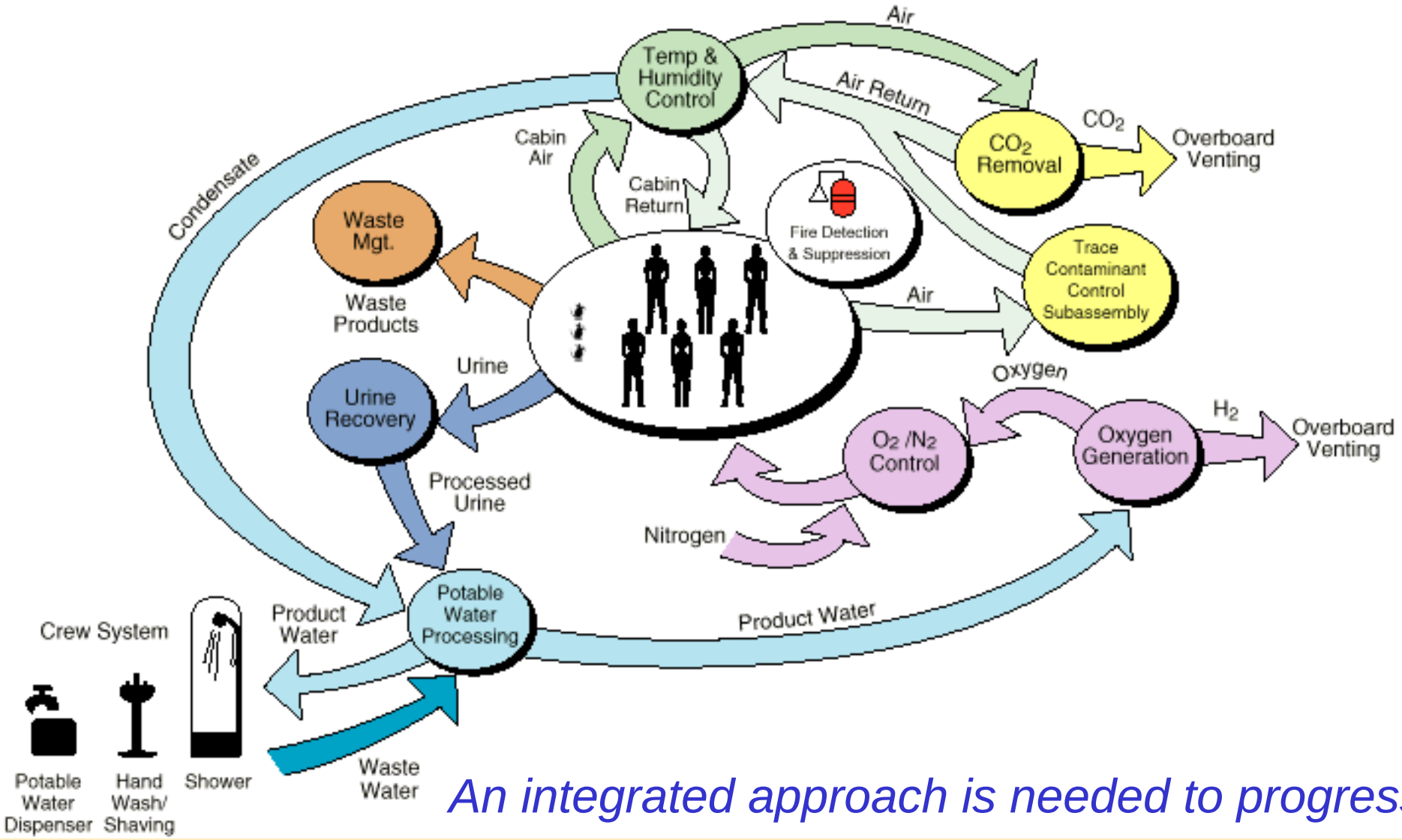
CELSS Benefits

- Has the potential to provide economic, psychological and mission operations benefits on long-duration missions
- In addition to the strict “economic” benefits of recycling *in-situ* regeneration of life support consumables can protect against unpredictable and difficult interruptions in logistics support

- Plus, people notice:
  - The availability of fresh foods such as grains, salad greens and other vegetables, and
  - The sense of autonomy inherent in a fully recycling life support system
- These can have a positive effect upon crew psychology and productivity—thereby contributing to the ultimate success of the mission.

Valentin Lebedev: Diary of a Cosmonaut

Space Station Regenerative ECLSS Flow Diagram (Current Baseline)



An integrated approach is needed to progress

Mission Assessments

- Initial Lunar (P/C only):
  - Short duration crew stays on Moon; limited testbed capability: some gravity, radiation, dust, thermal effects can be studied. Systems may be operated long-duration between crew stays to gather more testbed data (or not...)
- Later Lunar (Add Salad Machine, Bioregeneration)
  - Long duration crew stays on Moon enable a high degree of testbed capability with humans in the loop. A crew stay of 500 days could be used to create a high fidelity testbed of human and systems autonomy for Mars, and would be a commercially viable way to start
- Mars Transit (P/C with Salad Machine)
  - μ-g transit vs. possible use of lunar-level artificial-g during transits to/from Mars could have implications for the use of a lunar testbed
- Mars Exploration (P/C with Bioregeneration)
  - Short- or long-duration crew stays on Mars at 0.38 g

Example: Carbon Dioxide Control

Mercury	Apollo	Skylab	Orbiter	ISS
Two lithium hydroxide (LiOH) canisters operating in parallel.	Similar to Mercury design, but sized for 3 people and mission requirement	2 regenerative canister molecular sieve. Zeolite 5A for CO_2 removal and Zeolite 13X for water removal. CO_2 vacuum desorbed to space.	Similar to Mercury design, but sized for crew and mission requirements	4-bed molecular sieve. Two regenerative desiccant beds to remove water. Two regenerative Zeolite 5A molecular sieve beds to remove CO_2. CO_2 is heat and vacuum desorbed to space. Could be supplied to a Sabatier reactor, etc.

Drivers for CO_2 Removal Technologies

Energy Requirements

- The ISS CO_2 removal subsystem has the highest power penalty of any ISS life support subsystem (~ 3200 W-hr / kg CO_2). Current technology has a thermodynamic efficiency of about 3%.
- Current CO_2 removal & reduction technology in closed-loop mode (with Sabatier/oxygen recovery) will require ~ 5400W-hr / kg CO_2.

Carbon dioxide levels

- ISS requirement is 7000 ppm, compared to ~400 ppm Earth-normal
- Achieving lower concentrations translates directly into more energy consumption.

Desirement

- Develop CO_2 removal technology that consumes 10x less power than current Space Station technology for same performance.
  (or maintains substantially lower concentrations of CO_2 for no increase in power)

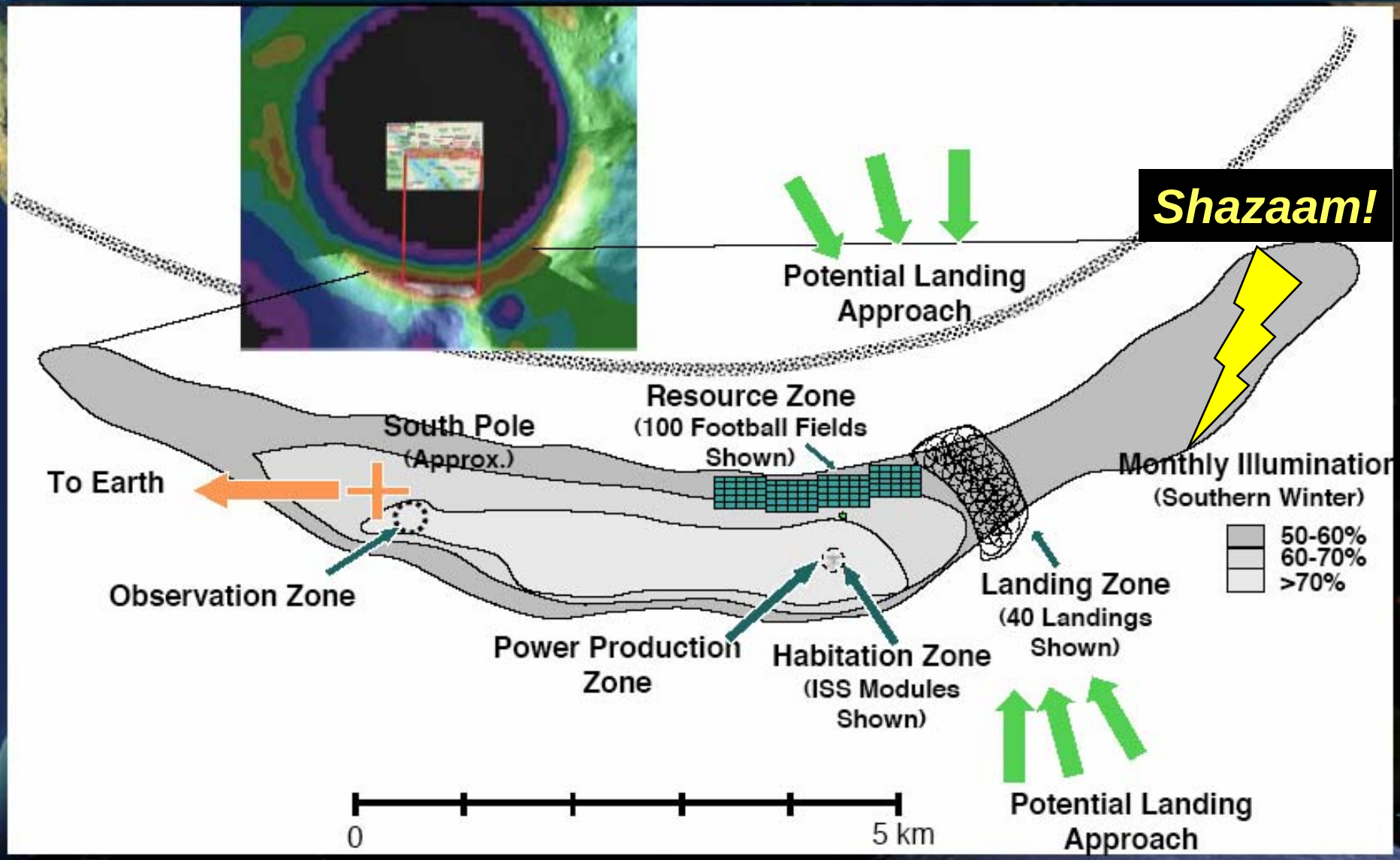
Advanced CO_2 Removal Technology

(Does low-energy electrolysis of H_2O, too)

Can replace its own parts, and you can eat the old ones . . .

Shackleton Crater Rim with Notional Activity Zones

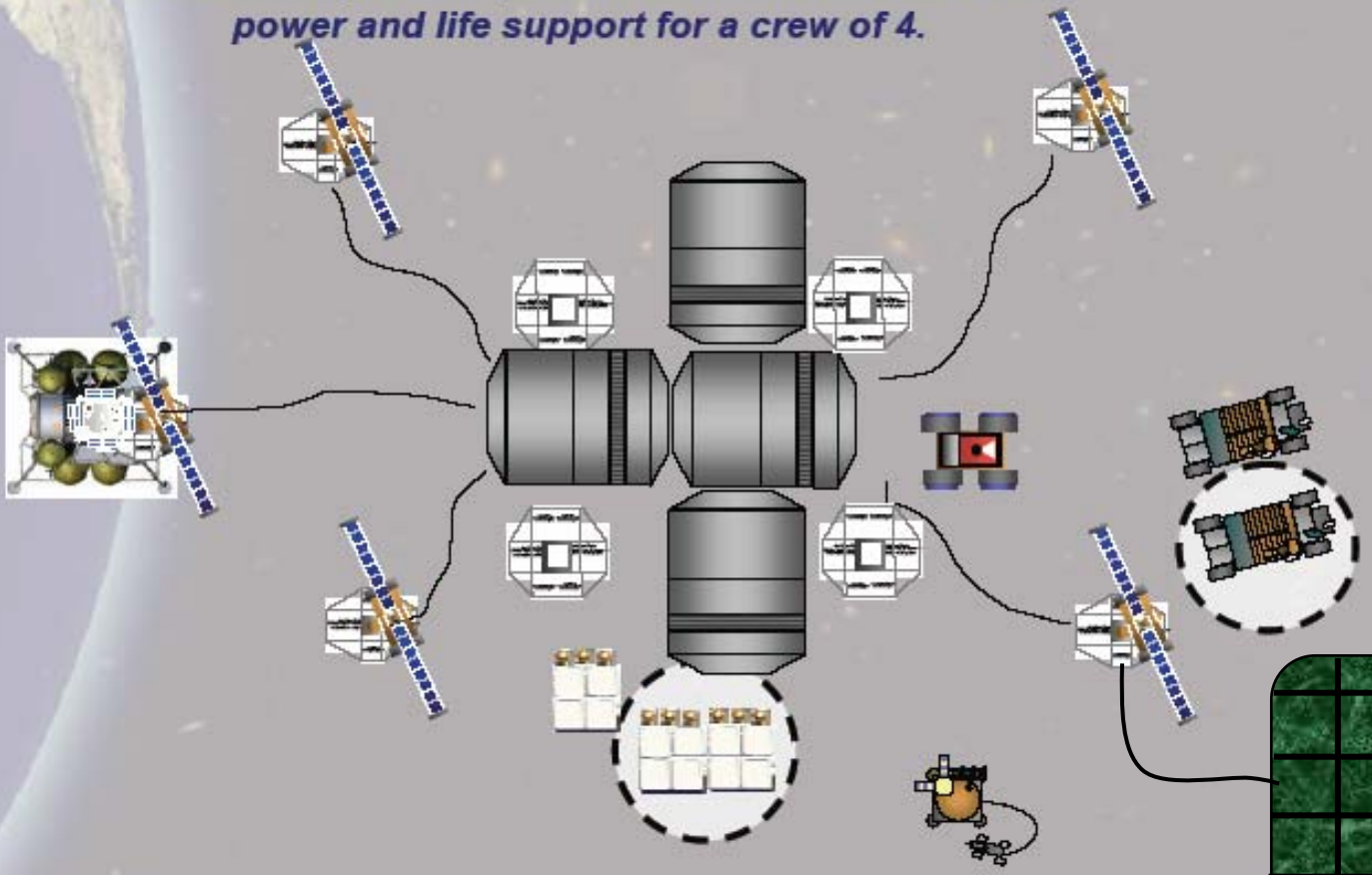
(Go Towards the Light!)



Key Points: Outpost Build up

Feed the Scientists – Make "Hay" while the Sun shines...!

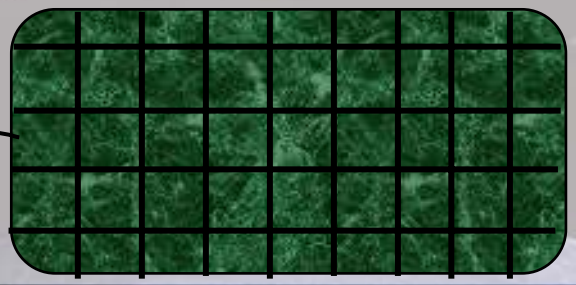
The capabilities represented here are the notional minimum systems and facilities that would be needed to support continuous 6-month stays on the surface. This level of buildup would provide infrastructure including power and life support for a crew of 4.



KEY

- Crew/Cargo Lander
- Solar Power Unit
- Unpressurized Rover
- Surface Mobility Carrier
- Habitation
- Power Storage Unit
- Logistics
- ISRU Module
- Pressurized Rover (2027)

Green House (< Mars)



Summary

Testbeds are Important, and (to some) the Whole Point

- Learning how to live and work on another planetary surface is one of the essential justifications for a Lunar return
- Ensuring you know what you are doing when you go farther out is why Lunar return can be important to later Mars exploration, and the human exploration of the asteroids and beyond

Lunar Exploration has Lessons to Teach: Advanced Life Support Use is One of Them

- ISRRU (CELSS) is a basic, *commercializable*, activity
- ISRU (local resources) plays well with CELSS to enable long-duration missions, enabling the “civilization” goal in the Vision.

We Need to Learn Those Lessons to Go to Mars *(and Beyond)*

- When you are on that long cruise to Mars, shouldn’t you be looking forward to that long cruise back?

Life Support:

Don’t leave home without it!

Earth: A proven, reliable, system. . .
. . .and, it’s BIOREGENERATIVE!