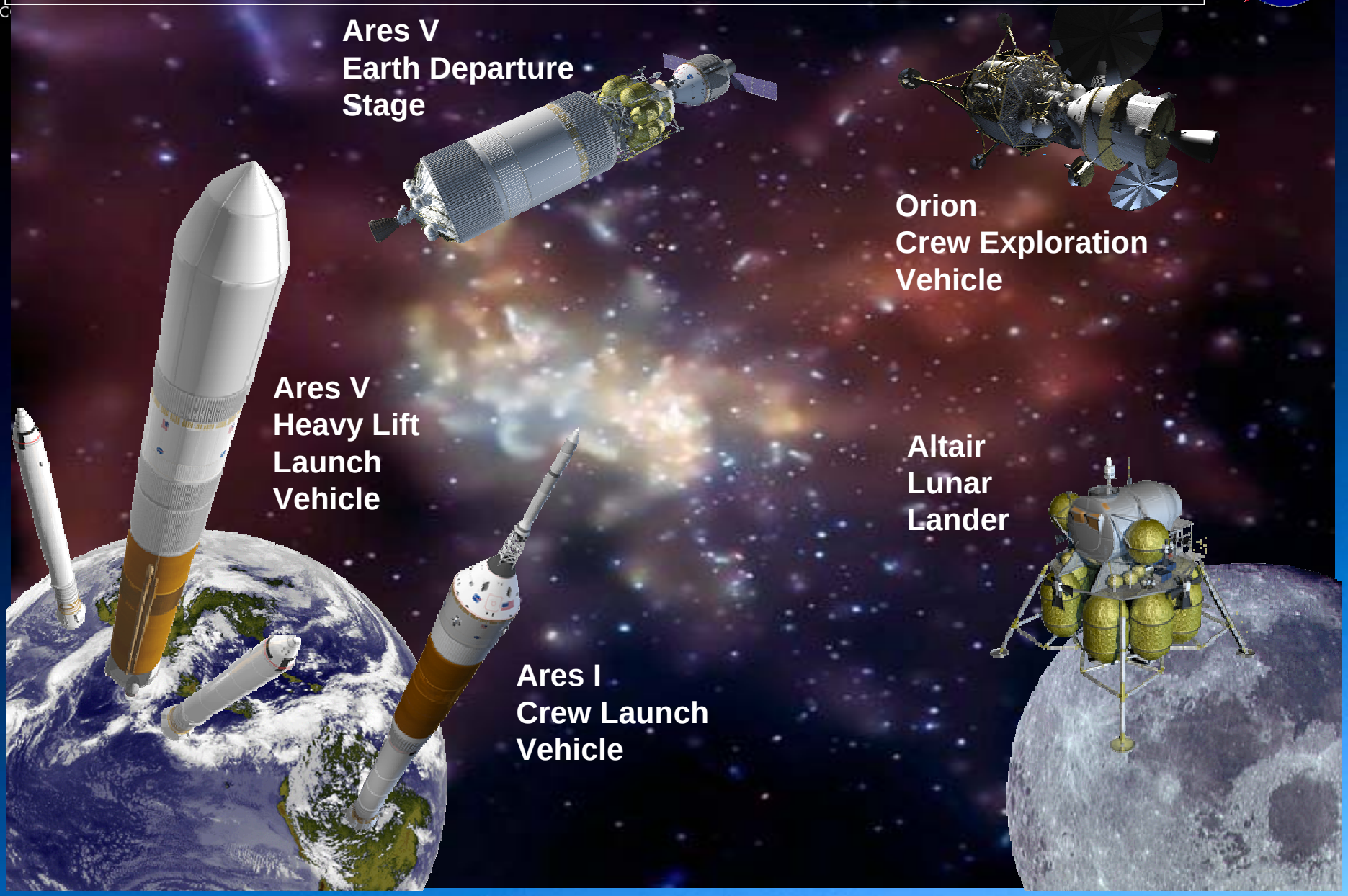
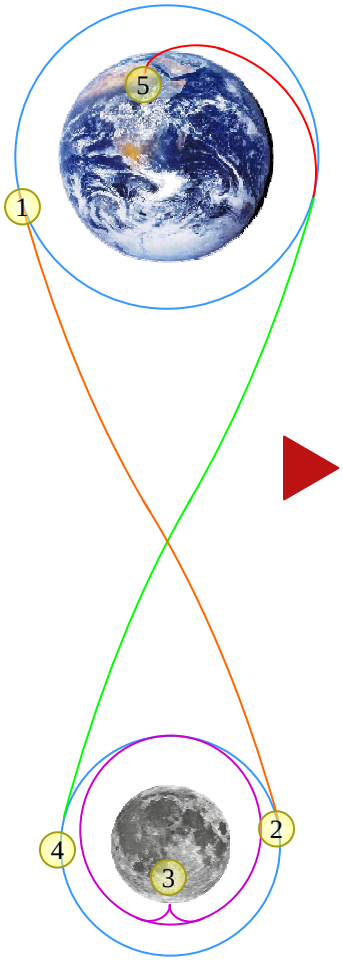
Lunar Surface Systems Architecture Overview

CONSTELLATION

Components of Human Lunar Return



Gear Ratios for Various Architecture Waypoints



1. LEO
2. Lunar Destination Orbit
3. Lunar Surface
4. Lunar Rendezvous Orbit
5. Earth Surface

A Kilogram of Mass Delivered Here…	…Adds This Much Initial Architecture Mass in LEO	…Adds This Much To the Launch Pad Mass
Ground to LEO	-	**20.4 kg**
LEO to Lunar Orbit (#1→#2)	**4.3 kg**	**87.7 kg**
LEO to Lunar Surface (#1→#3; e.g., Descent Stage)	**7.5 kg**	**153 kg**
LEO to Lunar Orbit to Earth Surface (#1→#4→#5; e.g., Orion Crew Module)	**9.0 kg**	**183.6 kg**
Lunar Surface to Earth Surface (#3→#5; e.g., Lunar Sample)	**12.0 kg**	**244.8 kg**
LEO to Lunar Surface to Lunar Orbit (#1→#3→#4; e.g., Ascent Stage)	**14.7 kg**	**300 kg**
LEO to Lunar Surface to Earth Surface (#1→#3→#5; e.g., Crew)	**19.4 kg**	**395.8 kg**

Introduction

- The Lunar Surface Systems Project Office was established in August of 2007 in the Constellation Program Office at JSC

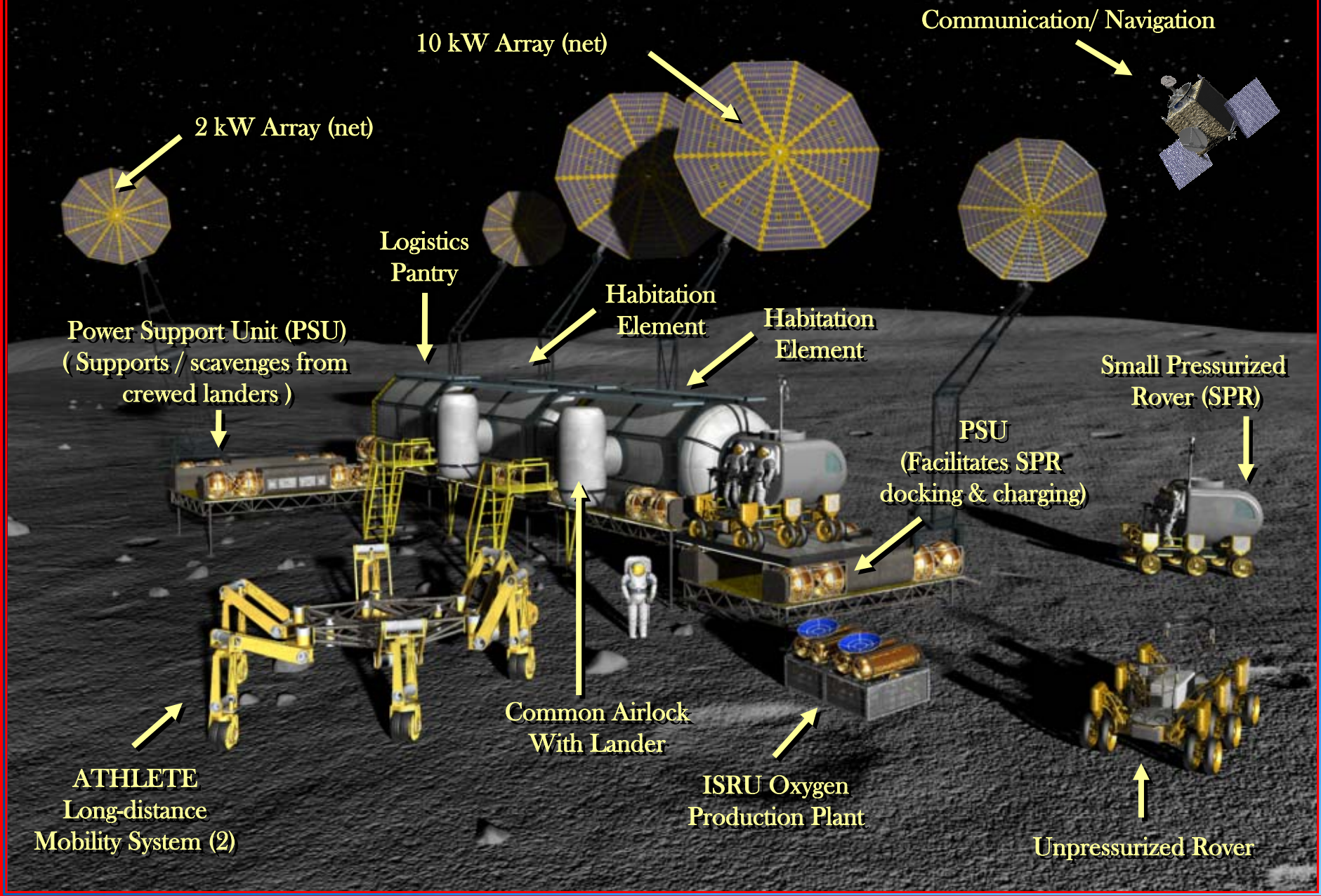
Mission Statement

Lunar Surface System's mission is to develop a sustained human presence on the moon to promote exploration, science, commerce, and the United States' preeminence in space, and to serve as a stepping stone to future exploration of Mars and other destinations.

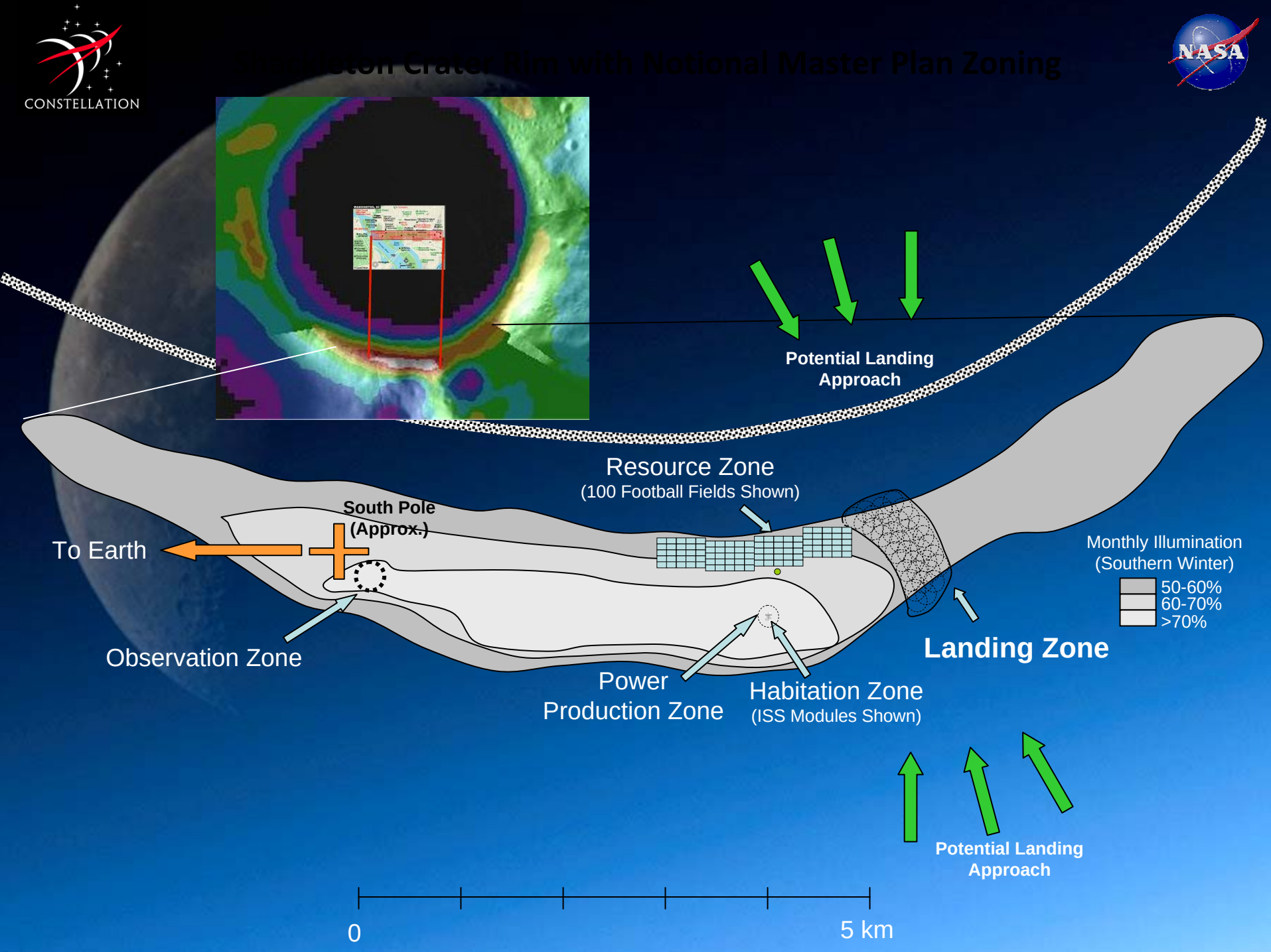
Lunar Architecture Framework

- Architecture desired characteristics
  - Minimally functional outpost capability established as early as possible
  - Outpost can be built at any rate with steadily increasing capabilities incorporated as desired: "go as you pay"
  - Pervasive mobility; ability to move outpost components to other locations on the lunar surface
  - Ability to pause outpost buildup at any time to accommodate sortie missions to other locations
  - Ability for international and commercial participants to contribute elements and systems that augment basic core capability
  - Core technologies and operations applicable to Mars exploration
  - Outpost configuration and capabilities (layout, mission duration, power) can be implemented to mimic Mars surface scenarios

Conceptual Lunar Outpost Surface Systems



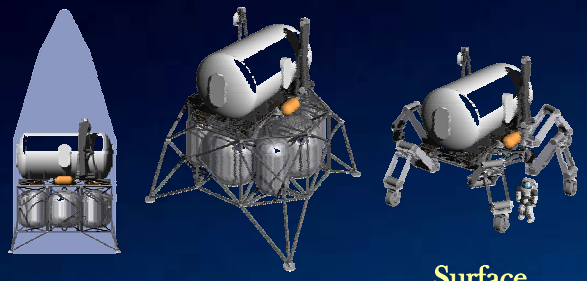
Shackleton Crater Rim with Notional Master Plan Zoning



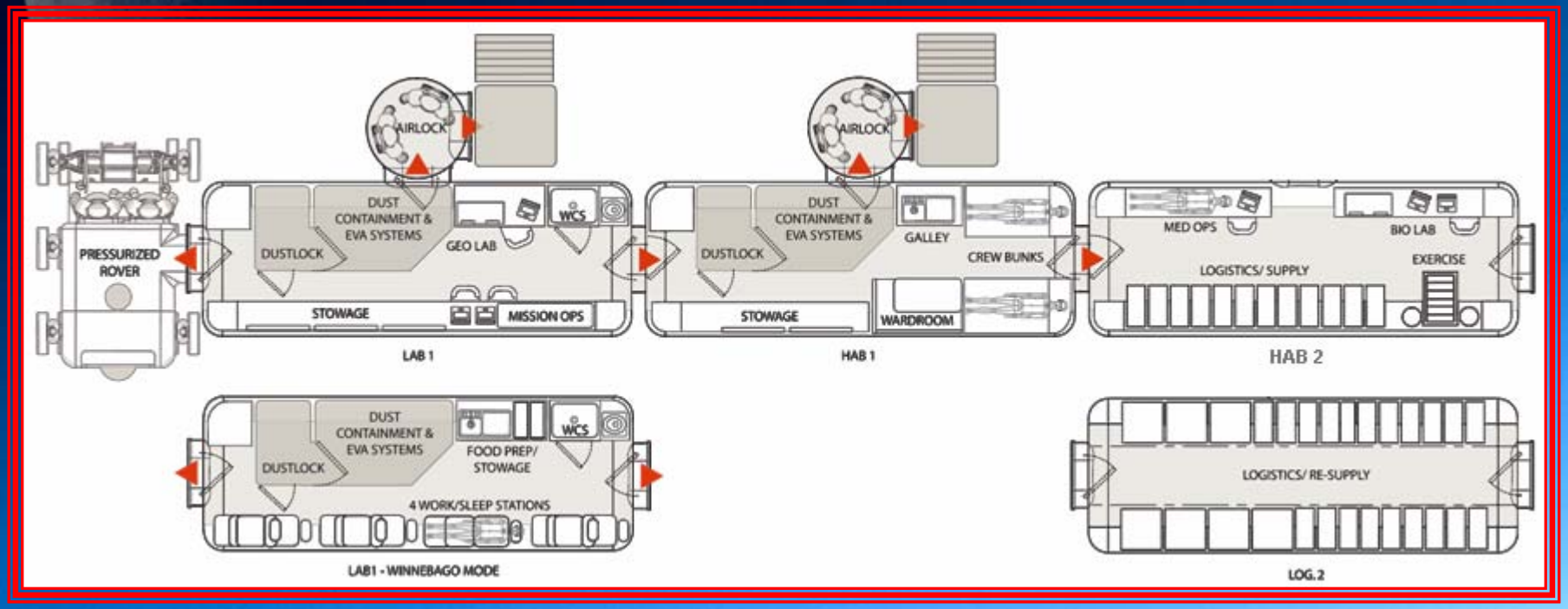
Notional Internal Habitat Layout

- Crew of 4
- Two Habs + converted Pressurized Logistics Module
- One Airlock each Hab
- Water wall SPE shelter
  - ~100 kg structure
  - ~1000 kg water (not Hab MEL)
- MMSE protection
- Pwr, lander I/F, comm on ICP
- Lab 1 = 6.6 mT
- Hab 1 = 8.5 mT
- Hab 2 = 3.6 mT (2 ports)
- OC Pwr = 13.3 kW
- OC Quiescent Pwr 2.6 kW

Delivery/Emplacement

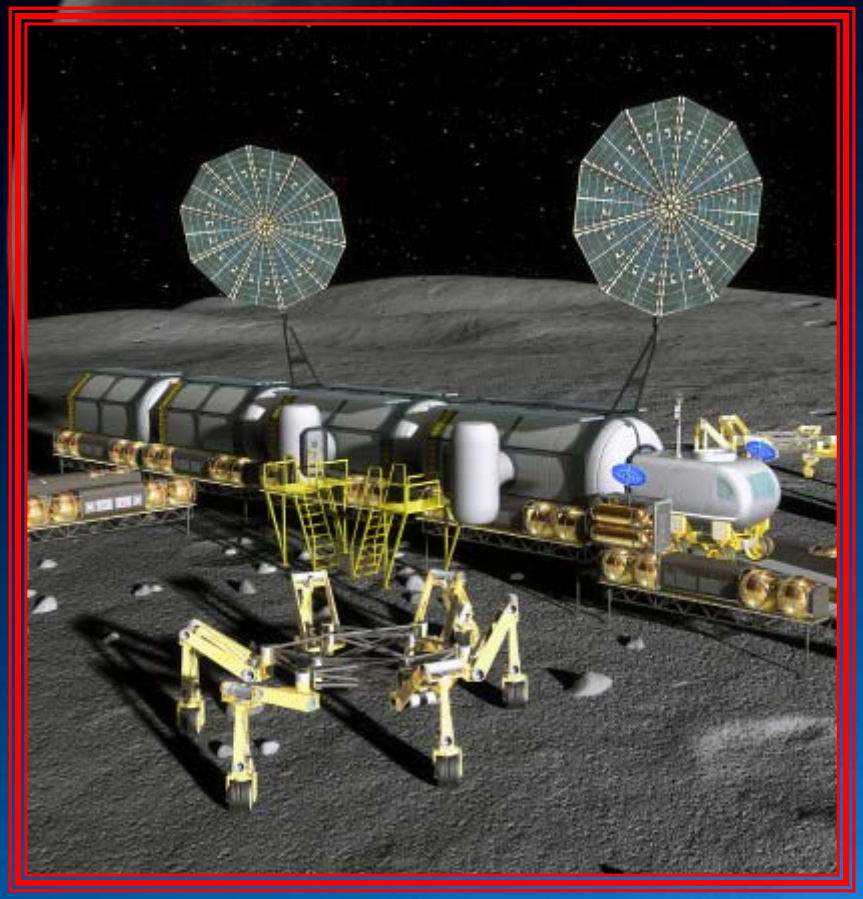


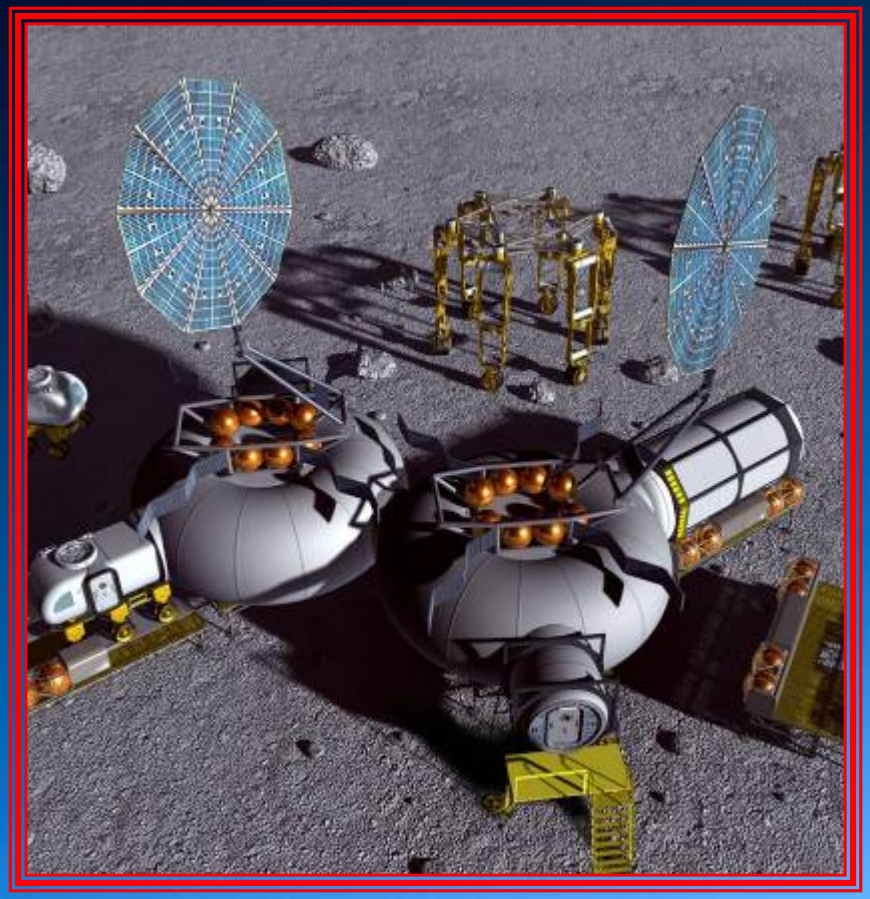
Launch Landing Surface Transport



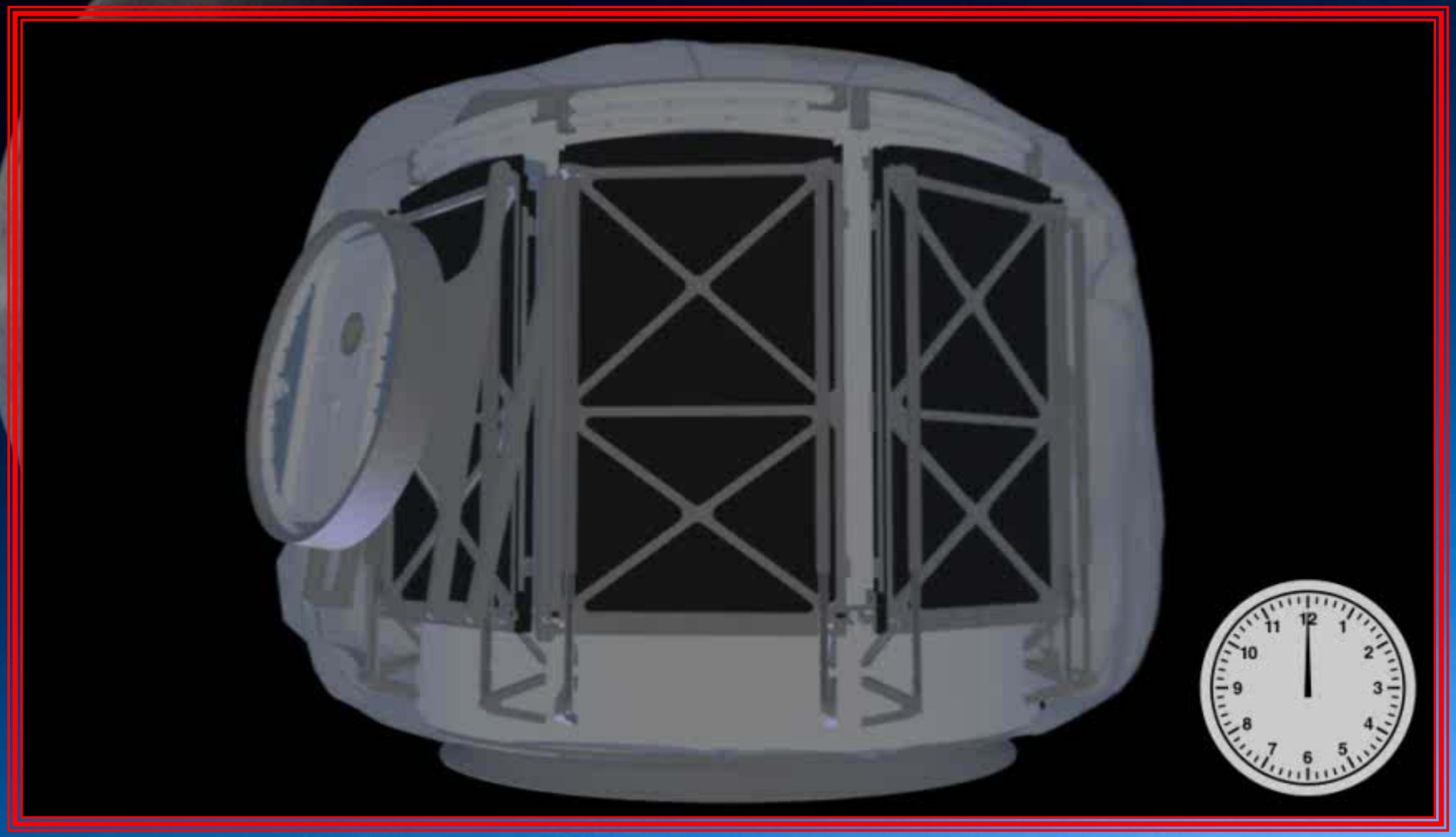
Alternate Architectures

- Also considering inflatable structures, but outpost functionality remains unchanged.

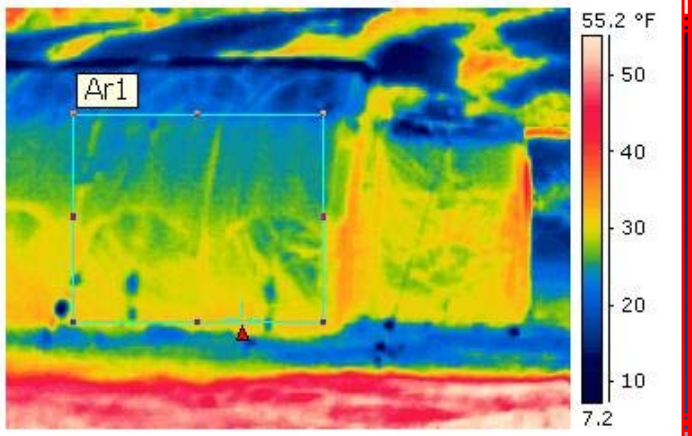


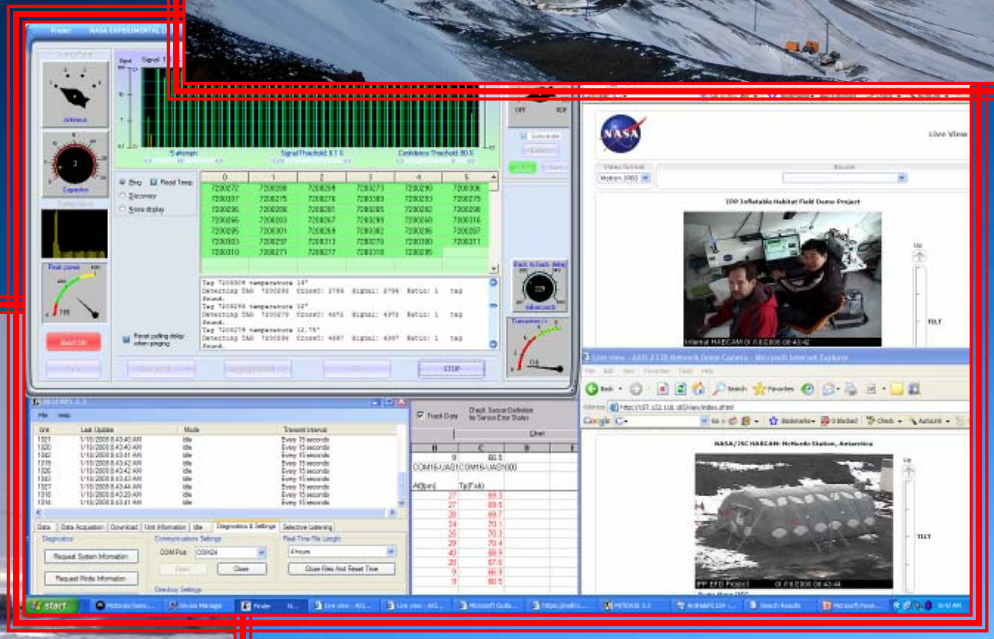


Inflatable Habitat Deployment Video
(click black screen in slide show mode to view)



Antarctic Inflatable Habitat Demonstrator





Mobility Concept Demonstrators

What is Lunar In-Situ Resource Utilization (ISRU)?

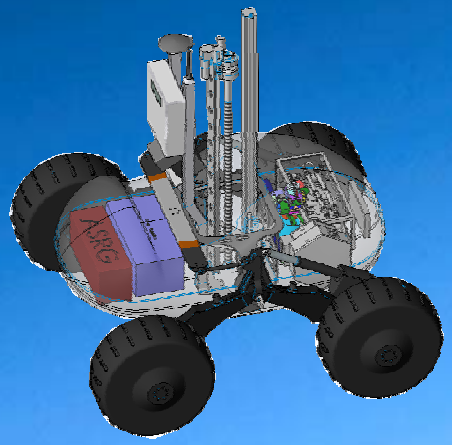
ISRU utilizes 'in-situ' resources to create necessary products and services for robotic and human exploration

In-Situ Lunar Resources

- 'Natural' Lunar Resources: Regolith, minerals, metals, volatiles, and water/ice
- Discarded Materials
  - LSAM descent stage fuel residual scavenging, tanks, etc. after landing (with Power)
  - Crew trash and waste (after Life Support processing is complete)

Benefits of ISRU

- Increased science and exploration hardware (instead of O_2 & water)
- Increased safety, crew exploration time, and self-sufficiency
- Technology spin-in/spin-offs help recycling Earth/space economy



Summary

- Challenges remain…

We're ready for the next giant leap

- The final outpost configuration is only achievable with Internal Partner and Commercial Partner contributions
- The Lunar Surface System is the next step in exploration that will enable us to continue on to Mars

Moon, Mars, Beyond…

Join us.

Lunar Surface Systems Supportability

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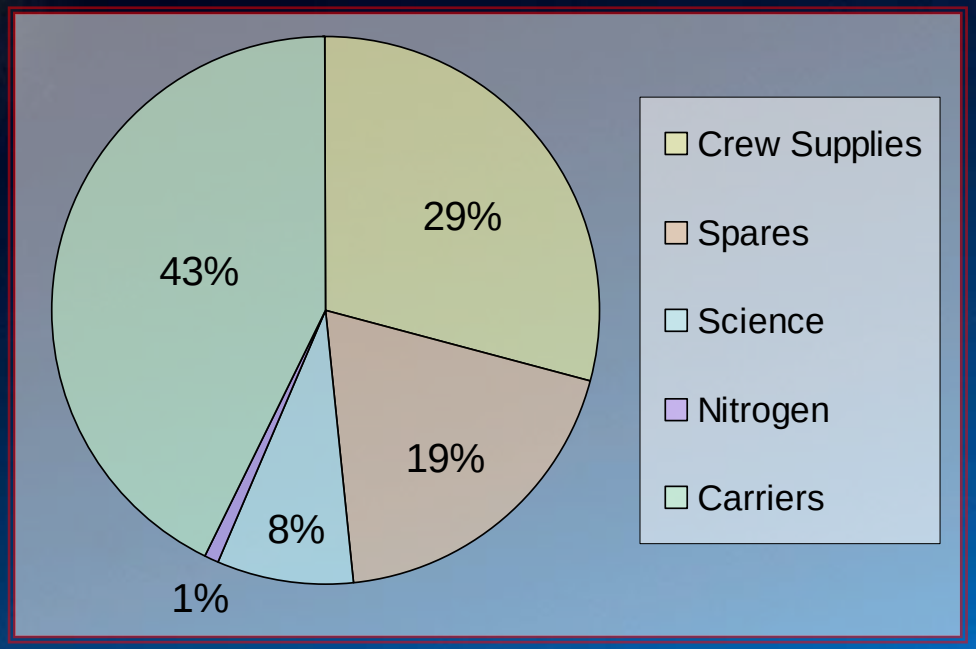
Introduction

- Lunar Surface Systems is currently addressing supportability in many areas:
  - Resupply Requirements
    - Crew Supplies; Spares; Life Support Consumables; Science
    - Carrier design and packaging (incl. alternative packaging study)
  - Integrated Logistics Support
    - Sparing Philosophy
    - Maintenance Concepts
    - Level of Repair Analysis
  - Reliability, Availability, Maintainability
  - Commonality
  - Scavenging, Reusability & Recycling
    - Reusable Lander - refuel in lunar orbit
    - Recyclable Lander - Reuse 80% of Lander mass for Outpost build-up & spares

Resupply Requirements

- Typical distribution of cargo and carriers:



- NASA is investigating ways to reduce mass in all resupply categories through repair, reuse and recycling
- Also looking at scenarios using reusable Lander and building infrastructure from recycled Lander parts

Ways to Reduce Crew Systems Resupply and Waste

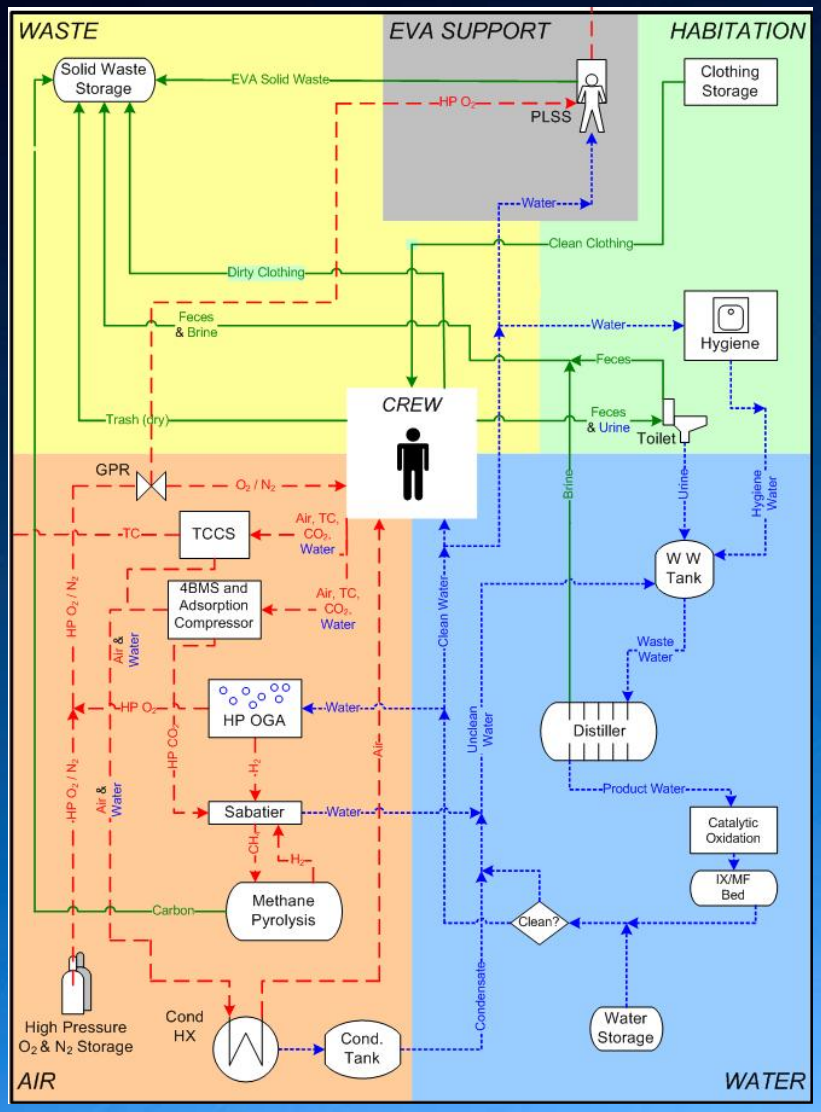
Category	
Food & Packaging	• Use larger, multi-serving containers • Use recyclable or compactable packaging • Grow some food in-situ
Utensils & Cooking	• Make utensils out of recycled plastics & metals
Personal Hygiene	• Use of launderable towels vs. disposable wipes • Community hygiene kit vs. individual items
Clothing	• Laundry vs. resupply • Super lightweight & compactable materials • Share clothing between crews, where possible
Crew Preference	• Use digital media; minimize size w/o impacting human factors
Cleaning Supplies	• Use of launderable towels vs. disposable wipes
Health Care Supplies	• Minimize size w/o impacting crew health or operations
Operational Supplies	
Trash & Waste Accommodations	• Trash compaction • Reuse/recycle other containers for waste storage

Ways to Reduce Spares Resupply and Waste

- **Increased reliability**
- **Increased redundancy (increases element mass)**
- **Repair versus replace**
  - ISS uses "Remove & Replace" philosophy where a failed Orbital Replacement Unit (ORU) is replaced with a new resupplied spare
  - For LSS, we're assuming R&R at the Shop Replaceable Unit (SRU) level and a surface-based repair depot
- **Commonality**
  - Share spares across LSS elements
  - Share hardware between Lander/Altair and LSS
- **Scavenging & Recycling**
  - Reuse Lander/Altair hardware to build & maintain LSS Elements
- **In-Situ Fabrication**
  - Make structural components from feedstock obtained from resupply, scavenging or regolith

Closed-Loop Life Support

- LSS is currently assuming significant closure of water and oxygen loops
- Production of oxygen from ISRU and scavenging of fuel cell water from Lander is also included



Ways to Reduce Carriers & Packaging Resupply and Waste

Types
Pressurized Logistics Modules (PLMs)
Unpressurized Logistics Carriers
Internal structures & racks
Cargo Bags
Foam & separators

- Reuse logistics modules as permanent habitation modules
- Minimize pressurized cargo demand to reduce number of PLMs required

- Use pallets as building blocks for Outpost elements
- Fill boxes with regolith and use for radiation protection

- Design internal structures to be re-configured for Habitat module outfitting (chairs, tables, etc)
- Design internal structures to serve as in-situ fabrication feedstock

- Build hangars for maintenance and science
- Fill with regolith for radiation protection & landing pad construction

- Concepts that require no packing material
- Materials that can be volume-reduced after use
- Materials with secondary application

Sustainability Applied to the Lunar Surface

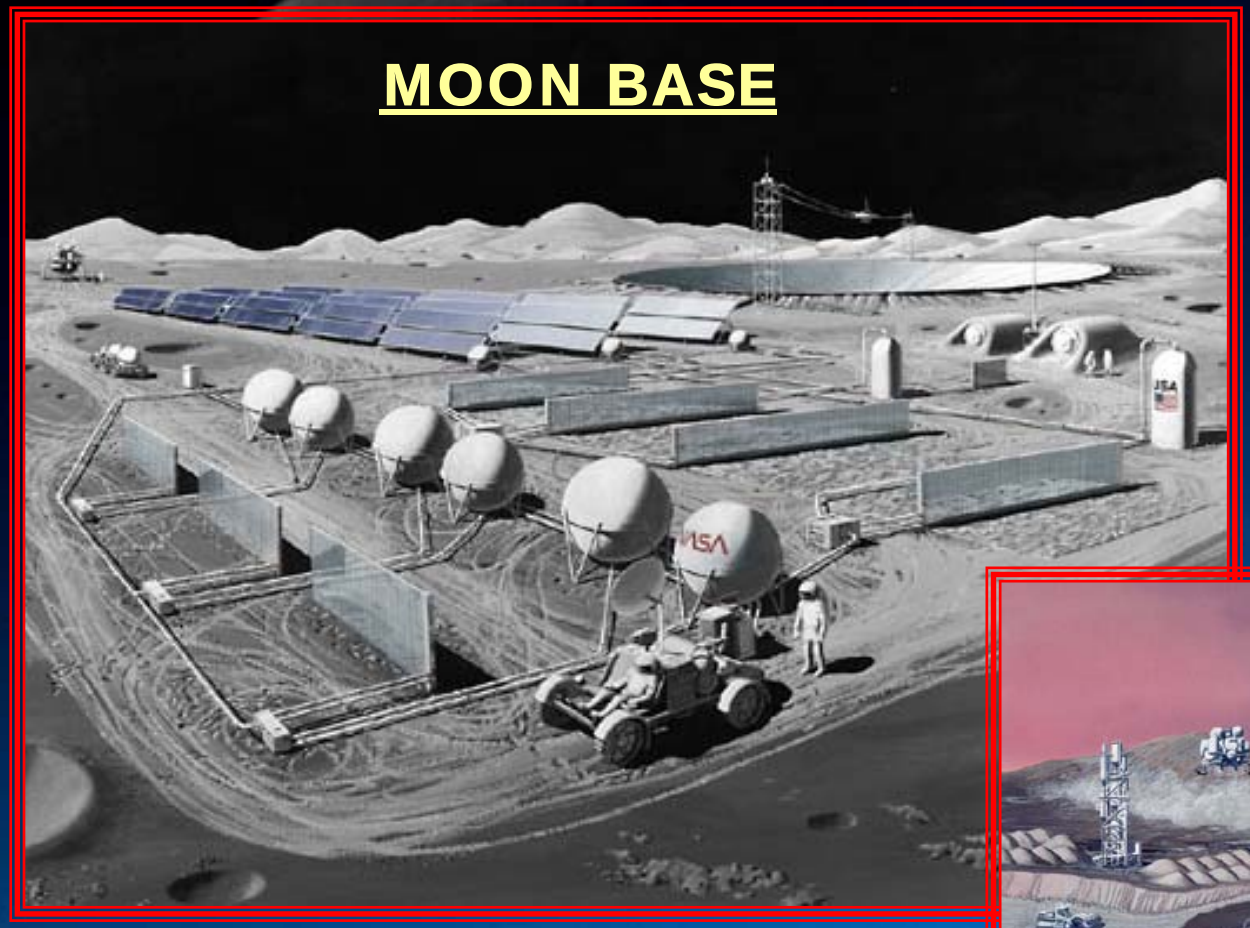
CONSTELLATION

CONSTELLATION

NASA

REMOTE SITE RESEARCH:

"THE DREAM"

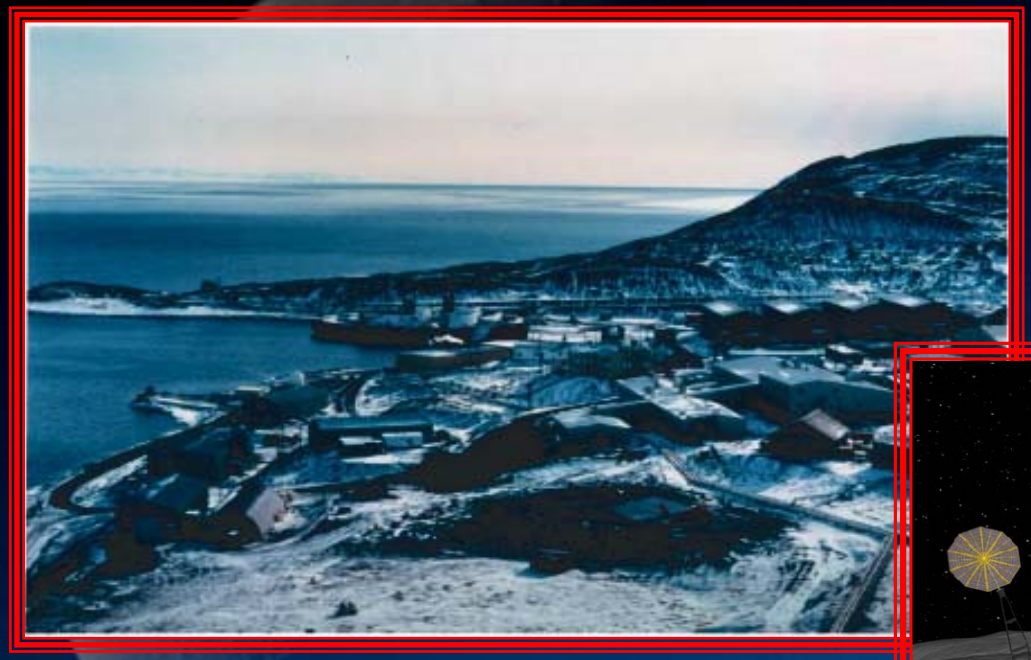


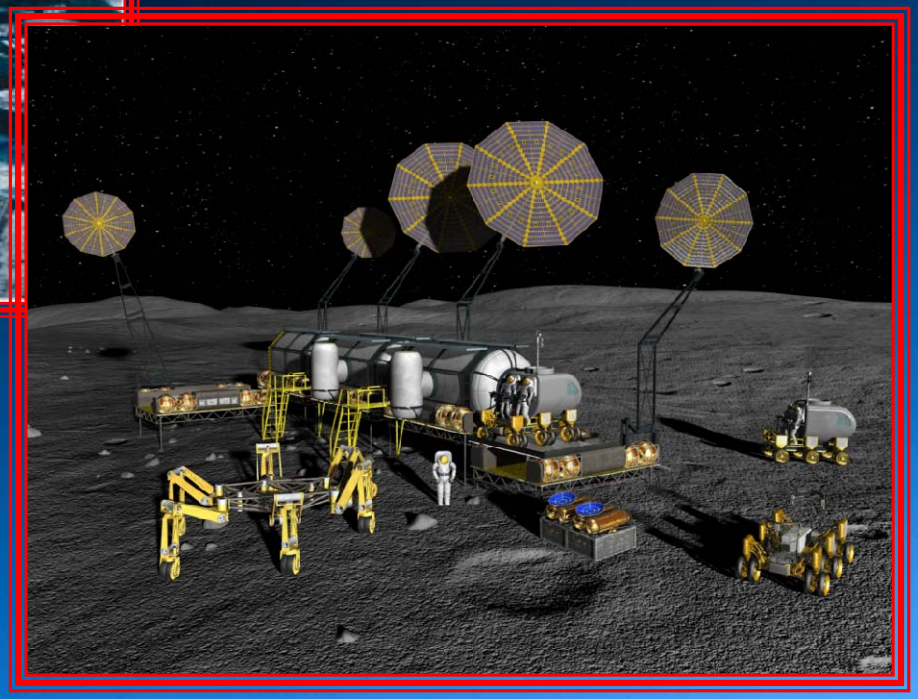
REMOTE SITE RESEARCH: *"THE REALITY"*

ANTARCTIC BASE

ARCTIC BASE

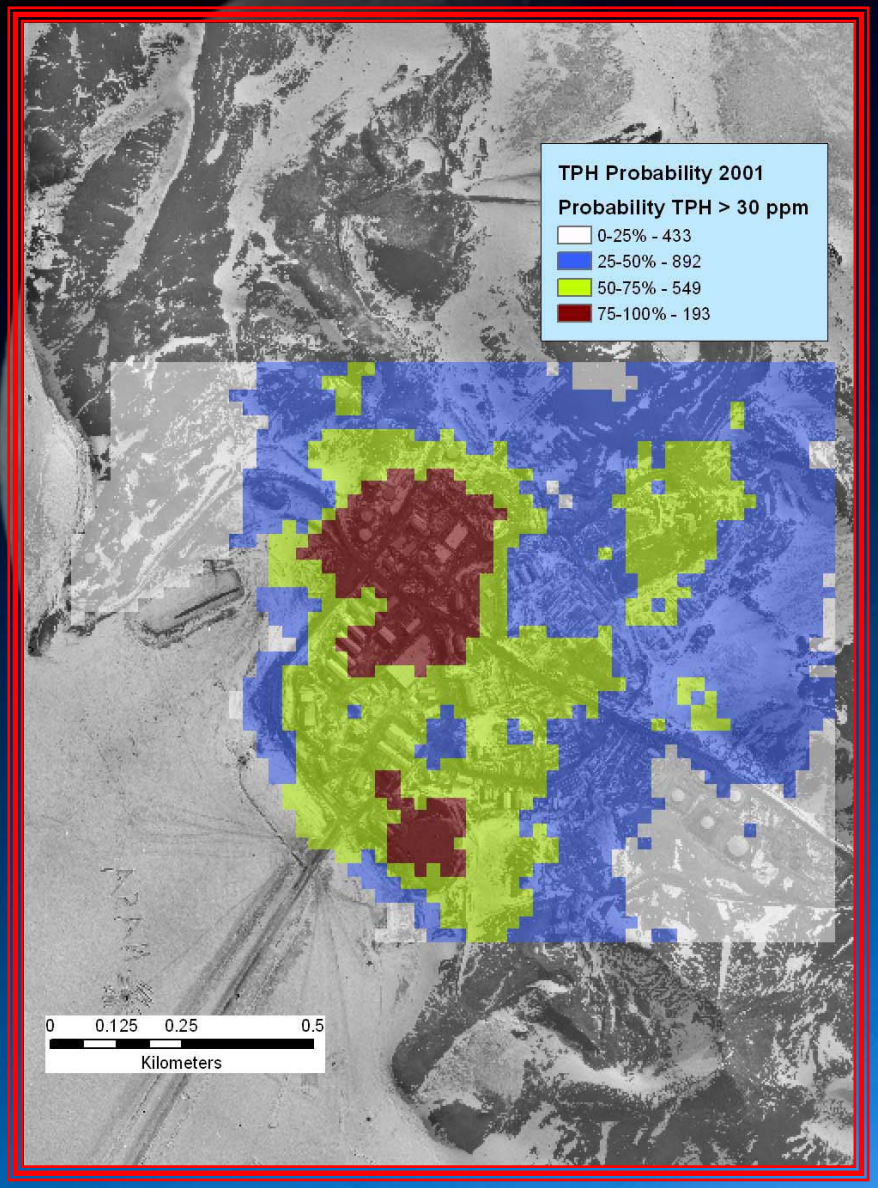
Operational Analogs





- **McMurdo Station and the Lunar base both have:**
  - Air or Spacecraft operations
  - Surface vehicular traffic
  - Worksites
  - Logistics operations
  - Community activities

Footprint Mission Impacts



- **Footprints are areas that are:**
  - Spoiled by human activities
  - degraded with respect to research value
  - Can occur due to unforseen activities such as recreation
- **This causes expanded research travel to access virgin territory**
  - Increases energy and consumable use
  - Increases required time
- **Footprints can be minimized through planning for all activities**

McMurdo Station Total Petroleum Hydrocarbon contamination footprint

Activities contribute solutions to both mass and environmental problems

- **Consideration of sustainability in the design of the lunar outposts, including approaches to address:**
  - Material obsolescence, availability, compatibility, evaluation of use of alternatives
  - Design decisions to ensure attainment of performance and safety (workers and crew) requirements
  - Ability to achieve requirements in a cost-effective and timely (schedule) manner
- **Explore options to incorporate long term sustainability concerns in the design and use of the lunar outpost including:**
  - Evaluation of impacts on surrounding environment due to use of the lunar outposts and lunar transportation systems, such as natural resource contamination that precludes future use
  - Assessment of how these lunar environmental impacts affect future mission activities, such as planned landings, exploration activities, or human habitation (under a range of duration and specific conditions)
  - Identification of design alternatives to consider and address impacts that undercut the long term sustainable NASA presence on the moon
  - Prioritization and implementation of design that supports sustainability throughout mission execution over the mission's lifecycle and minimizes impacts to current and future efforts.

Use Terrestrial Lessons…

- Recycling
- Leadership in Energy and Environmental Design (*LEED*) building principles
- Green chemistry principles
- Others

…to make the shift from heroic survival to sustained research

Mount Everest Recycles

Legacy of accepted expendables shifted to oxygen bottle recycling and reuse as bells

LEED Principles

- Sustainable Sites
- Water Efficiency
- Energy & Atmosphere
- Materials & Resources
- Indoor Environmental Quality

Green Chemistry Principles

- Prevent waste
- Design safer chemicals and products
- Design less hazardous chemical syntheses
- Use renewable feedstocks
- Use catalysts, not stoichiometric reagents
- Avoid chemical derivatives
- Maximize atom economy
- Use safer solvents and reaction conditions
- Increase energy efficiency
- Design chemicals and products to degrade after use
- Analyze in real time to prevent pollution
- Minimize the potential for accidents

Conclusions