Lunar Colony Phase 2

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Phase 2 Goals

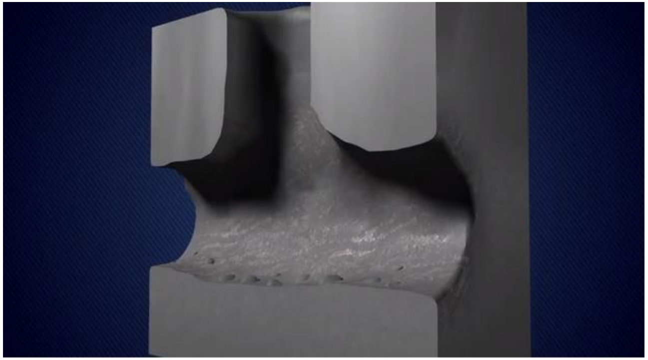
- Establish permanent equatorial settlement
- Expand polar settlement to house additional crew
- Begin lunar prospecting and mining
- Construct lunar material processing and construction facilities
- Construct far-side telescope array
- Construct maglev rail system between equator, polar outpost
- Construct launch pad at equatorial settlement & polar settlement
- Construct space elevator to service settlements
- Expand solar & nuclear power facilities
- Begin large scale food growth
- Expand total lunar population to 300 by end of Phase 2

Location

- Phase two will be concentrated at the equator and a suitable location for the telescope
- The permanent outpost for human presence will be located in a pit in Mare Tranquilitatis

Equatorial Base

- Construction sequence:
  1. Create inflatable surface observation deck to oversee automated construction
  2. Build elevator shaft
  3. Excavate tube
  4. Escape hatches
  5. Use microwaves to heat seal the sides (done simultaneously with steps 3 and 4)
  6. Build support beams
  7. Use lunarcrete to build floors and air locks
  8. Build homes on first floor
  9. Pressurize first floor
  10. Move in first group of people
  11. Complete middle and bottom floor
  12. Pressurize middle and bottom floor
  13. Continue expansion and move-ins



Expansion and Research of Power Systems

- At the onset of Phase 2, primary research will begin on nuclear fusion of Helium-3 and microwave transmission of power.
  - A small experimental reactor developed on earth will be used to generate power from nuclear fusion of small amounts of lunar Helium-3.
  - Microwave generators will be used to transmit power over varying distances on the lunar surface, and when the technology readiness level increases, to various lunar facilities.
  - Primary research will be carried out in use of lunar Thorium for the Space Molten Salt Reactor (SMSR)
  - Proof of viability of solar sails and/or free flying mirrors based on Phase 1 research.
- As Phase 2 progresses, solar power plant capacity will steadily be increased, from 100 KWe to 500 KWe (tentative). Efficiency increased using Phase 1 research
- The capacity of the SMSR will also be expanded to 500 KWe to maintain redundancy, and the number of fuel cells will be increased to operate at a constant 50% (250 KWe) power for lunar night.

Reasons to pursue In-situ Resource Utilization (ISRU)

- Reduction in mass of payloads transported from Earth
- Reduction in cost of launches
- Manufacturing and repair capabilities, and production of life support consumables on the lunar surface lead to reduction in risk.
- Increased flexibility for missions and research
- Expansion of power systems: Manufacturing of solar cells/arrays, potential use of lunar thorium or helium-3 for nuclear fuel
- A step towards a self-sustaining lunar colony

In-situ Materials Processing and Manufacturing

- Early development: Two temporary inflatable structures located at Shackleton and covered in regolith for shielding, interlinked by conveyor belts.
- Replaced by permanent structures constructed from in-situ materials by end of phase two
- STEP 1: Regolith transported from mining sites to the Processing facility on cable trams
  - Beneficiation - the finer part separated from the coarser part - using a coarse sieve and electrostatic separation. Ilmenite extracted by electrostatic separation.
  - Extraction of Volatiles - including Hydrogen, Helium-3, oxygen, sulfur, fluorine (captured for use)
  - Extraction of Oxygen, metals, and FiSe alloy by molten silicate electrolysis.
- STEP 2: Extracted materials transferred to Manufacturing facility
  - The metals Aluminum, Iron, Magnesium, Calcium and Titanium are used to manufacture parts for construction and repairs.
  - Silicon ilmenite, and some other metals are used to manufacture solar cells
  - Ilmenite undergoes a reduction reaction with hydrogen to produce water at 600-900°C.

$$FeTiO_3(s) + H_2(g) = H_2O(g) + TiO_2(s)$$

  - Processed regolith and coarser rejected regolith is sintered using microwaves to produce bricks and slabs for construction.
- Both steps are operated by robotic assistants, with engineers overseeing the process and maintaining the robotic systems.

Extraction of Volatiles

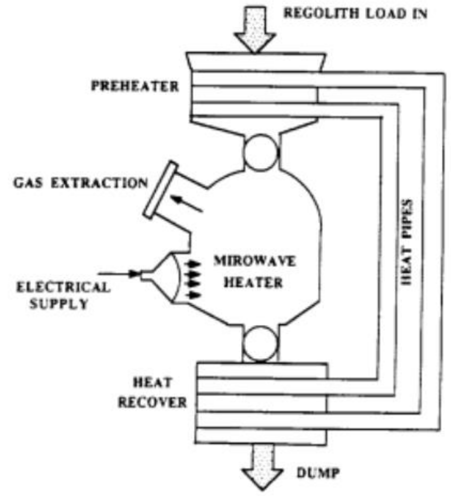


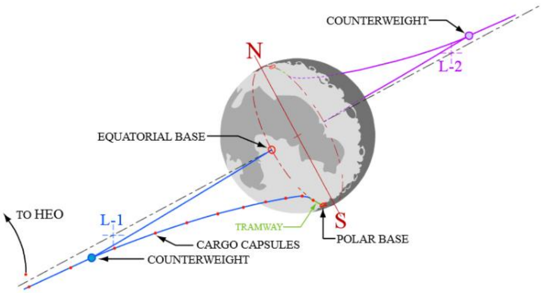
Fig. 8. Arrangement for the use of a microwave heating technique to process regolith fines.

Hurdles to In-Situ Resource Utilization

- Mechanical conveyance systems for the transport of regolith from excavation sites will require a lot of power, and their moving parts will be at risk from lunar dust and micrometeorites. During the later phases, pneumatic system could be used which has no moving parts and is contained in a closed pressurized volume.
- Low efficiency of current extraction methods, especially for oxygen and water - research will be carried out to find better extraction approaches
- Economic viability is still considered dubious - will have to be proven during phase 2 by demonstrating small-scale ISRU capabilities using cost-effective and efficient methods of processing and manufacturing.
- the largest hurdle is the large expenditure of power required during the transportation of regolith between sites and microwave heating to high temperatures. This will be overcome by the recycling of energy within the ISRU system and the expansion of power systems of the base.

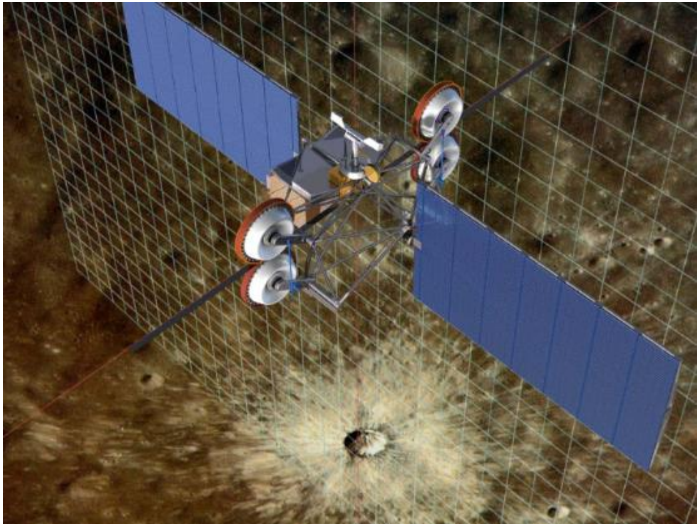
Lunar Space Elevator

- Ribbon cable reaching from equator to counterweight past L1 or L2
- Can be further connected to Polar station or other sites across surface
- Cheap transportation of cargo between Earth orbit and lunar surface
- Would make other infrastructure construction much easier and cheaper
- Unlike Earth Space Elevator, could be constructed with existing composite fibers such as Kevlar, M5, Spectra due to 1/6th gravity



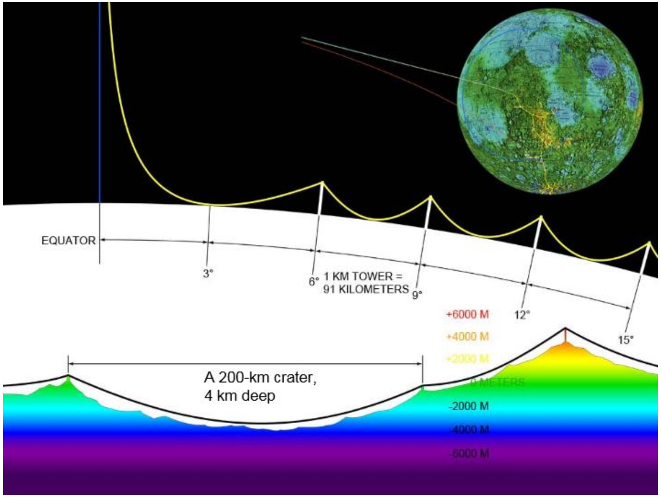
Lunar Space Elevator: Design

- Two segments:
  - Tapered segment up to 25,000 km
  - Thick uniform segment 180,000 km long
- End will reach into LEO and be able to send and receive cargo from there
- Mass of thicker segment will take place of traditional counterweight
- Will actually be multiple cables, connected at intervals
  - If one breaks, others will take load until fixed
  - Will increase cargo throughput of elevator
- Climbers:
  - Cargo canisters on wire trusses
  - Two pairs of wheels clamp to cable, drive climber up & down
  - Powered by large solar arrays & batteries when in shade (very small portion of journey)



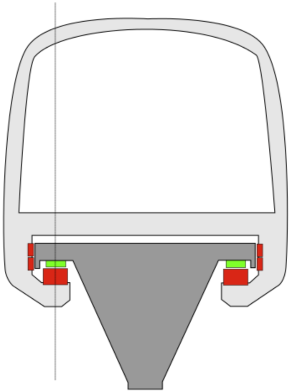
Lunar Space Elevator: Construction

- Fleet of Orbital Transfer Vehicles
  - Equipped with high efficiency propulsion systems (ion engines, solar sails)
  - Transfer many small sections of cable from LEO to L1
- Cable segments assembled at L1, then deployed
- After lunar manufacturing in place, addition tramway constructed to polar base
  - Cable suspended above surface by a number of tall towers
  - Allow direct connection to polar base, and other sites across surface



Maglev Transportation

- Magnetic attraction and repulsion are used to allow frictionless travel
- Electromagnets oppose the gravitational force to levitate the car as well as provide acceleration and deceleration
- The moon is ideal for maglev transportation due to its lack of atmosphere

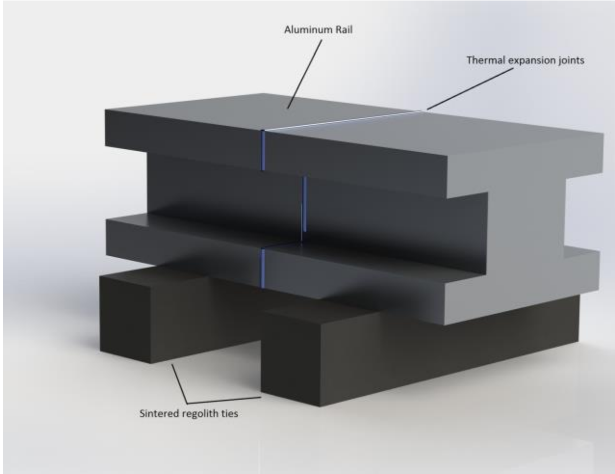


Maglev Transportation

- Advantages:
  - Very fast
    - 4.5 hours between equator and south pole (600 km/h)
  - Low power usage
  - Low maintenance requirements (no physical contact with track)
- Design:
  - Aluminum extracted from regolith, used for power rails
  - Sintered blocks of regolith support the aluminum rails
  - Rails can be covered in solar panels to provide power
  - Connects equatorial base, polar base, and far side telescope
  - Two tracks, one for each direction
  - Pressurized cars for astronauts, unpressurized cargo carriers

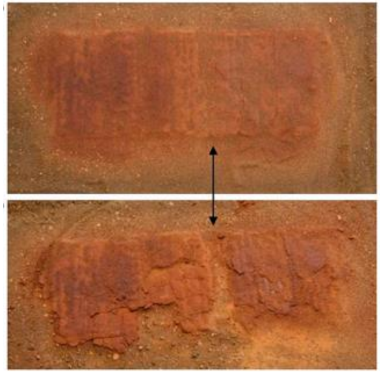
Maglev Transportation

- Construction:
  - Robots create a flat space for the track, using gathered regolith to produce blocks
  - Followed by robots that process regolith for aluminum and lay the power rails
  - Cars could be delivered from Earth
- Issues:
  - Thermal expansion - gaps connected by flexible material allow rails to expand while still conducting electricity
  - Power loss due to rail length - would need alternate power source at night



Equatorial Launchpad

- Rocket exhaust near lunar surface kicks up dust, which can damage nearby infrastructure (much like sandblasting)
- Can use sintering to create a hard ceramic launchpad
- Requires heat source - concentrated sunlight or microwaves
- Could place in small crater to prevent the spread of dust
- If no crater is available, can create a circular wall of regolith around the site



Telescope

- NEO observatory
- Center for lunar based astronomy and astrophysics
- Optical telescope made from mostly regolith (similar design to liquid mirror telescope)
- Later will be expanded to large scale observatory including radio, gamma ray, x-ray, and infrared telescope
- Powered by solar arrays manufactured in situ using lunar materials

Food Production

- Automated farming https://www.youtube.com/watch?v=nyHxG4EVCSo
- Aeroponic technique

Geoponics

Strengths: • Traditional method of growing crops, greatest body of research available	**Weaknesses:** • Soil will cost much more to ship
Opportunities:	**Threats:** • Not considered to be as clean as other methods leading to more disease

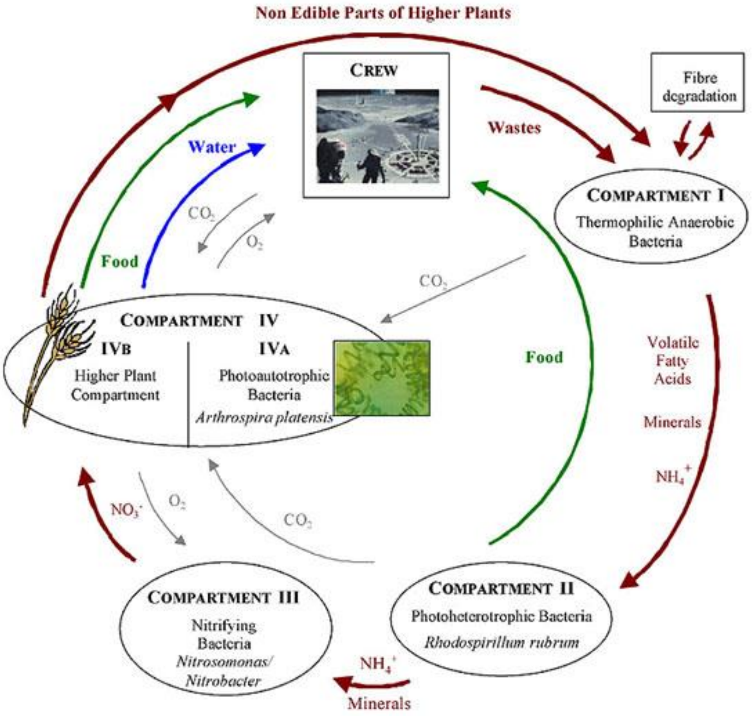
Hydroponics

Strengths: • Very little or no soil is needed for plant growth • Reduces the land needed to cultivate crops • Reduces amount of water used • Slightly cheaper than aeroponics	**Weaknesses:** • Nutrients need to be constantly replaced. • Will require more water than other growth methods
Opportunities: • Plants tend to thrive more in this type of system than in geoponic systems, leading to a larger crop yield	**Threats:** • Has been shown to lead to more diseases than aeroponics

Aeroponics (selected for use)

Strengths: • Eliminates the need for soil • Nearly does away with having to use water • Minimizes the area needed to grow crops • Cleaner than other types of growth methods	**Weaknesses:** • Slightly more expensive than hydroponics
Opportunities: • Reduce water usage • Plants tend to thrive more in this type of system than in geoponic and hydroponic systems, leading to a larger crop yield	**Threats:** • If the equipment to maintain the plants malfunctions the roots will rapidly dry up

Outpost Life Support



Water Production

- Research has still not conclusively shown that enough water is on the moon to support all processes. At this phase, it is planned for enough research to be obtained during phase one in order to optimize harvesting lunar water. However, if enough water cannot be obtained several plans have been made such that the colony will at least not be reliant on any pure water from the earth.
- A combination of techniques will be used:
  - Harvesting oxygen from lunar surface (from either regolith or ilmenite) and combining it from earth sourced hydrogen
  - Fuel cells, which combine hydrogen and oxygen to produce electrical energy and water during the lunar night
  - Hydrogen reduction of Ilmenite. Ilmenite is an attractive source of water because there are substantial reserves of ilmenite present in lunar soil, and it can undergo reduction with hydrogen at 900-1050 °C, a relatively low temperature compared to other metals.

Task	Time in Years								
	1	2	3	4	5	6	7	8	9
Equatorial Shelters									
Small-scale Mining and Processing									
Maglev and Observatory Site survey/preparation									
Initial Space Elevator Construction									
Polar and Equatorial Base Excavation									
Equatorial Base Construction									
Maglev Construction									
Observatory Construction									
Permanent Polar Habitat Construction									
Food growth systems									
Space Elevator "Tramway" Construction									

Works Cited

- All references and pictures cited in project report