Barton Peveril Sixth Form College

Luna For Living

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Contents:

Part 1 - Propose a commercial activity to be undertaken on the Moon, describing the major components and processes and indicating in general terms how such activity might generate income and profit.

Part 2 - Design a permanent Moon base capable of sustaining at least 20 persons, maximizing self sustainment. Costs need not be stated but solutions should seek to be economical i.e. not extravagant in use of resources.

Part 3 - In support of the requirements of Parts 1 & 2, design a transportation system for carriage of people and materials to / from the Moon on a regular basis (i.e. what is required is a proposal enabling multiple trips rather like a ferry service). The transport system should be capable of carrying a load of at least 2500 Kg between the surfaces of Earth / Moon in either direction. Costs need not be stated but solutions should seek to be efficient and economical.

Introduction

Our plan is to access the moon and conduct experiments and not only survive, but to thrive, creating a colony on the natural satellite within which people will live and work for the betterment of mankind. The moon could potentially act as a hub in outer space for use in future moon missions, due to the total energy requirement of sending an object from the moon to outer space being much less than that of an object being launched from Earth as a result of the difference in gravitational field strength. Resources on the moon may be collected for use at the same time, and these could potentially be used to create structures for the colony. The great exposure to sunlight that the moon receives would allow for a bountiful harvest of solar energy, used to power the moon colony or in fact the Earth through the use of energy transmission.

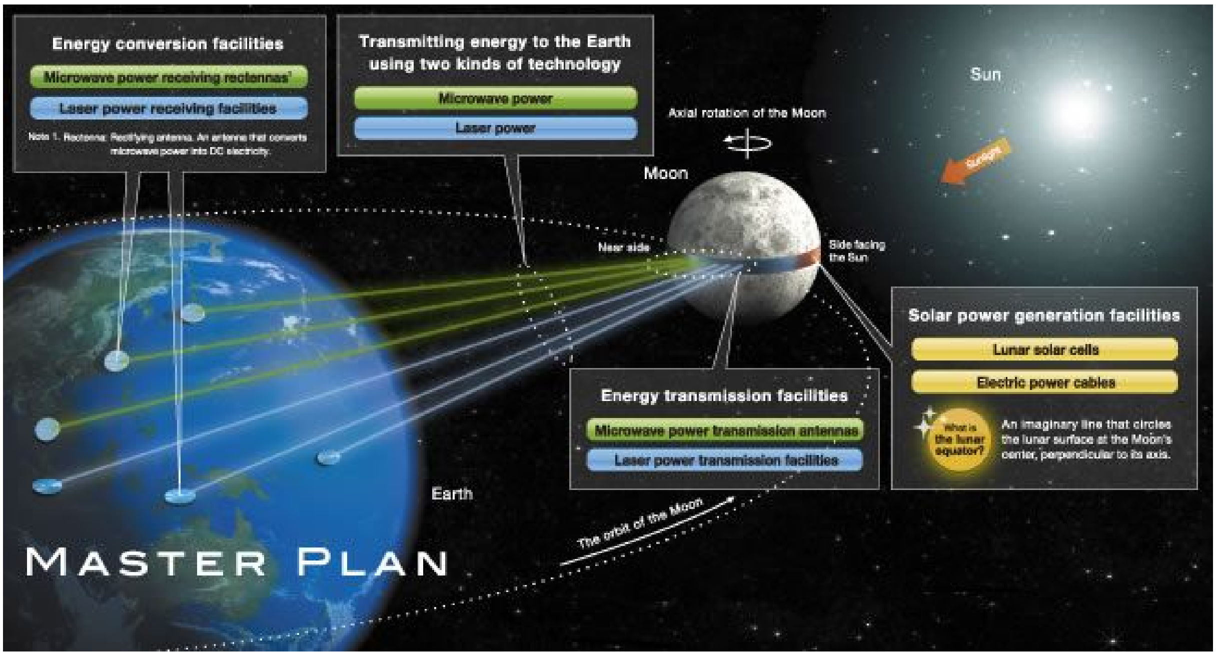
Energy Production

On the moon, much more energy can be produced by solar panels, since the moon possesses essentially no atmosphere which scatters or absorbs the sun's light, thus on the moon solar panels are a lot more efficient.
This energy can be beamed via microwaves down to the earth to be received by some kind of mobile array positioned on a boat or floating pad that will move around the Pacific and/or Atlantic so as to make sure it lines up with the moon's beam as frequently as possible.
On earth, one solar panel can produce 6.83 Watts/meter squared (one panel is 1.155m^2).
This equates to 590kW / m^2 in 24h - The energy required for oxygen production through solid oxide electrolysis for one day is approx. 748354909 Joules (750MJ). This means that for oxygen production to be sustainable, around 1200 solar panels are required, equating to around £240,000 costs (These figures are elaborated on later on, in the ISRU section).
(The dimensions of one Solar Panel: 1.65m * 0.70m. Cost to make one, which can be done on the moon, using a centrifuge to spin monocrystalline silicon - £200)
The Earth's atmosphere absorbs around 23% of sunlight, while the moon has negligible atmosphere, meaning a solar panel on the moon would produce around 30% more power on the moon compared to Earth. (Thus approx. 213W/ m^2/ 24h)
While solar power is an incredibly effective means of power generation, should the location they are placed end up in darkness, the users would be without power for a range of time that can be unpredictable, so reliance would be placed upon batteries, but since the lunar day and lunar night last approximately 14 days each, this would require vast amounts of batteries and very careful planning and rationing if necessary, hence why the location is of vital importance (covered later).

Another form of reliable power would be the use of nuclear energy, where a constant energy output can be achieved. This is already in development by NASA, with the heat produced from a nuclear fission reaction being transferred to a stirling engine, with the Kilopower reactor - http://www.nasa.gov/directorates/spacetech/kilopower

"To generate electricity, the researchers used a liquid metal to transfer the heat from the reactor to the Stirling engine, which uses gas pressure to convert heat into the energy needed to generate electricity. For the tests, the researchers used a non-nuclear heat source. The liquid metal was a sodium potassium mixture that has been used in the past to transfer heat from a reactor to a generator, says Palac, but this is the first time this mixture has been used with a Stirling engine." - Describing the potential of nuclear power on the moon. *[8]*

Below is a concept by Shimizu of how power generated by a ring of solar panels on the moon could be sent down to receivers on earth using Microwaves or lasers, which can tie in to the commercial section of this task, as excess power not being used by the colony may be transmitted back to Earth and sold to electrical grids around the planet, therefore generating income from the moon's surface.



Credit - Shimizu - https://www.shimz.co.jp/en/topics/dream/content02/

Scientific Experiment Facilities

General size

For another commercial activity, we intend to construct scientific research facilities inside some of the domes. These facilities will be used by the astronauts on the moon on behalf of scientists who wish to pay money in order to experiment on different topics in space, for example how plants grow in lower gravity, etc. These facilities will have to be larger than the general size of the living spaces deployed on the moon to allow for large machines and testing areas. For example, one experiment could be to study the effects of low gravity on certain earth-designed gravity based items (e.g possible projectile motion experiments). These however would require an adequate amount of room to cover large distances, which would give more accurate and precise results. These spaces would have to be between 2-5 times the size of an average living space to allow for small to medium sized experiments.

Possible problems and solutions

A few problems arise when working with slightly unpredictable and sensitive circumstances in a delicate and dangerous environment, and so these will have to be reduced and monitored at most times. One problem could be within the context of the experiment itself, and how it affects its surroundings. For example, the growth of a dangerous plant could cause an allergic or harmful reaction with the inhabitants, which would require medical attention. This may be difficult however as the available treatment may not reduce the issue, or could exhaust resources for a later, more crucial date. Another problem could be an unexpected explosion or pressure difference which could damage the internal and external conditions of the barrier between the dome and space. This would be extremely dangerous as it could cause the dome to be completely compromised, resulting in loss of equipment, regress in expansion of the base or a fatal incident involving an inhabitant of the base.

These problems would need to be addressed in multiple ways in order to reduce both the likelihood of an event occuring and the consequences of such an event. The first and most important way to reduce this would be a large plan and report of each experiment. This plan must include but not limited to things such as:

- An overview of the experiment
- A hypothesis of the outcome of the experiment
- A risk assessment
- A safety protocol
- An evacuation and risk reduction plan
- An outcome report of the experiment (This should be written after the experiment has concluded)

These will help guide the experiment and will make it easier for the inhabitants to control all outcomes of the experiment, especially if it were to go wrong.
Another way to reduce problems posed by the experiments would be to wear specialised suits which would help reduce the risk of harm coming to the inhabitants within the dome. These suits should be light and flexible to allow for flexibility and free movement, but would also have to be heat resistant, air tight and would have to be able to withstand large amounts of force from a penatritive source such as a shard of glass or rock. They would also preferably need to be able to withstand outer space for a limited time, and would have to be insulated in order to keep the inhabitant alive and able to function.
Another way to reduce the risk posed by problems would be the reinforcement of the outer dome. This would allow for the dome to withstand a large force or pressure difference, which would reduce the overall risk of catastrophic failure of the outer dome. This could be achieved by a thicker layer of regolith rock on the outside of the dome, and a stronger skeletal structure in order to stop the dome from being

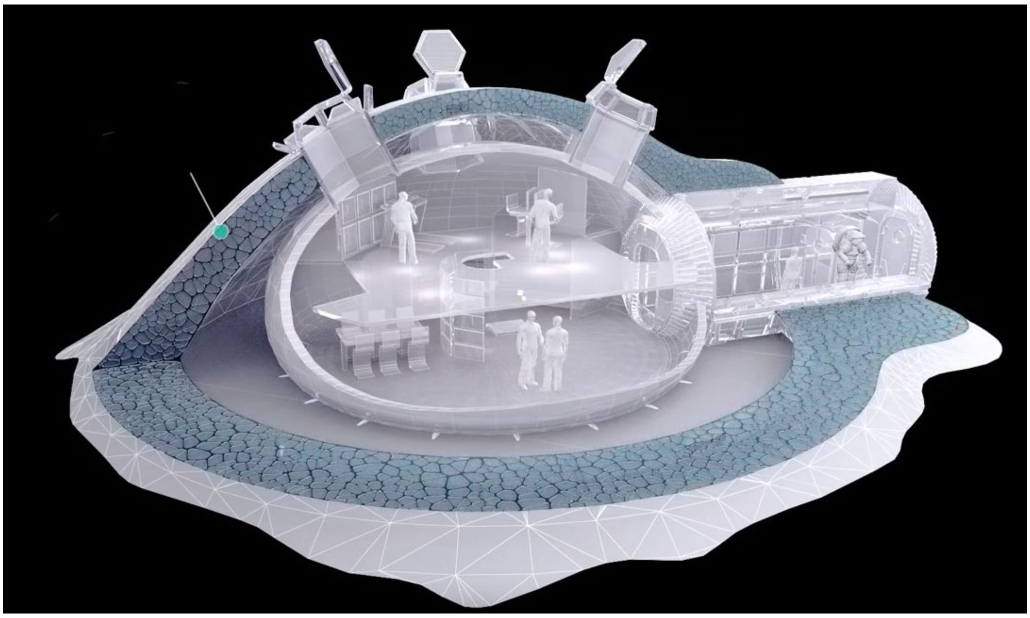
compromised from debris from a failed experiment, or from a large pressure difference which would usually cause the dome to collapse.

Base Design

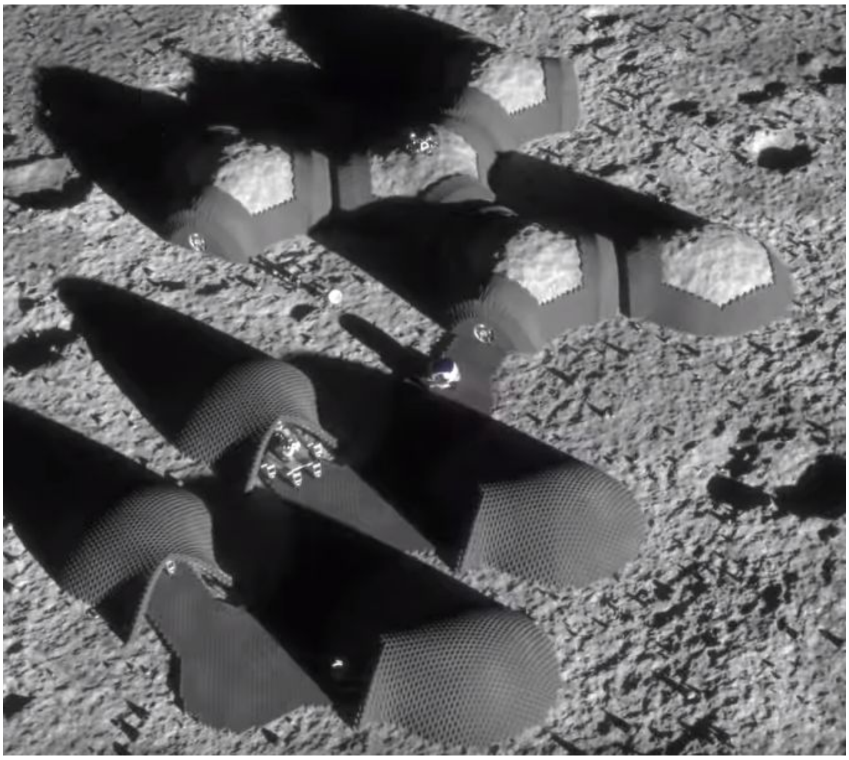
The design of our moon base is a series of inflatable domes which once fully inflated will have an exoskeleton structured around them and then will be reinforced with moon regolith, which will be periodically replaced. Once each dome is erected, the soil and rock underneath it will be dug down beneath the dome, allowing for essentially unlimited expansion of the moon base over time. Each dome will be able to sustain around 4 to 5 people thus around 4 to 5 housing domes will be required, as well as several other domes for growing food, storing equipment and scientific experimentation. Each dome will be around 10 m in diameter, with multiple floors, as well as the bottom dug out to provide more space. They will each have an airlock which will be around 4 meters in length, and will be used to store the suits used by the inhabitants. They will help maintain a stable internal pressure and atmosphere and create a bridge between each dome. The dome's will originally be made out of a flexible polymer capable of expanding as planned. The airlock will most likely be composed of metals to maximise safety of the astronauts by maintaining a strong exoskeleton which will keep the base from deforming and collapsing. To minimise the use of electricity, natural light will be utilised through the use of automated windows. These will help to brighten up the inside of the bases to reduce energy consumption, but will have to be closed at set intervals to block direct sunlight, which could cause the domes to become unbearably hot, or even set fire.

The base should be divided into different sections for different purposes. For example, the bottom of the dome could be used as a main living space for the astronauts with tables and chairs, and possibly forms of entertainment, which will give the astronauts a place to relax during down time. It would also give a common place of conversation which would allow for the astronauts to plan and discuss later events, and could be used as an assembly point for announcements within the dome.

<u>Concept Image</u>



Below: A construction material synthesised in situ using lunar regolith.



https://www.youtube.com/watch?time_continue=92&v=SdycFkvJam0&feature=emb_logo

Food/Agriculture

Until food growth becomes fully sustainable, supplies will be sent with food and water. The methods of food growth include using a centrifuge to produce artificial gravity in order to grow crops such as potatoes.
We may also use the EDEN ISS project being run by the european space agency at the moment which aims to create an artificial environment in hostile conditions to efficiently cultivate and produce food which would be greatly helpful on the moon. With the use of this project's technology we could be capable of producing 268 kilograms of food in 9 months with relatively low power consumption overall.[9]

To sustain themselves Astronauts they must consume between 2,700 to 3,700 calories per day.

"For example, an astronaut on the ISS uses about 1.83 pounds (0.83 kilograms) of food per meal each day." - https://www.nasa.gov/vision/earth/everydaylife/jamestown-needs-fs.html

A single astronaut will require around 0.83kg of food per meal per day, and at 3 meals per day this would equate to 2.49Kg per person per day. For the minimum total of astronauts present, the total weight would equal 49.8Kg of food per day. Around 0.12kg of each of these food units is packaging, and it has been included to

show the full weight which is relevant due to the necessity of transporting the food in the initial stages of the mission.[19] [20]
Potato plants may take anywhere from 70 to 120 days to grow to a harvestable level, so food needs to be available during this entire period plus extra amounts to cover uncertainties in yield, crop quality and of course it needs to be recognised that humans cannot simply live on potatoes alone, though they are a very good provider of vitamins and minerals and a medium sized potato with a diameter of 5.7 - 8.2cm provides 110 calories per unit. Theoretically, if the minimum of 20 people in the base were to attempt to live on potatoes alone then 455 potatoes would be required to provide the recommended 2500 calories required as a daily intake.

Hydroponics, the use of a liquid medium to grow plants, is a method that replaces the need for nutrient rich soil, instead opting to provide nutrients in a liquid. This is a major advantage as hydroponic farms can be as big or as small as required, and they use, on average, 20% less space for their growth. Another major benefit of using hydroponics is the growth speed, which can be increased by up to 2 times that of soil growth. An estimated 20 times less water is used during the growing periods, making the process highly efficient in terms of water usage when compared to soil usage, reducing the need to carry excess weight during transport periods. Hydroponics also requires fewer pesticides and herbicides, further reducing the amount of weight required for farming systems.

On the other hand, the hydroponic systems can be very expensive to set up, with the returns of the system being low in comparison to the initial costs, also, where the reuse of water within the system is concerned, if diseases are introduced, they can spread throughout the plants within the system. Despite these difficulties, this is even more efficient than soil farming, making for a viable and reliable source of food.

ABOVE - The SPREAD hydroponics shelving units shown above are making use of space by building vertically, as well as using highly efficient LED lights to provide *energy to the plant for photosynthetic processes. This system also uses automation to manage the farm - https://cityos.io/view.competitor/28875/Spread*

Storage of food items is also of vital importance, especially in the long term, as foods will spoil over time. Thankfully, methods of doing this have already been tried and tested in space and are still in frequent use aboard the ISS. Freeze-drying or dehydrating the foods removes all water from the food items and all that is required to make them consumable to a good standard is the addition of water. Good examples of foods that behave well when dehydrated include oups and egg products. Fresh foods may be consumed but will only last up to about 3 days within space, especially when temperatures are high. Meat products may also be stored and kept for extended periods of time through the irradiation of the product, killing all bacteria present during packing. These are perfectly safe to eat according to the World Health Organization.

How materials will be acquired (water, oxygen, etc.)

Sabatier Reaction

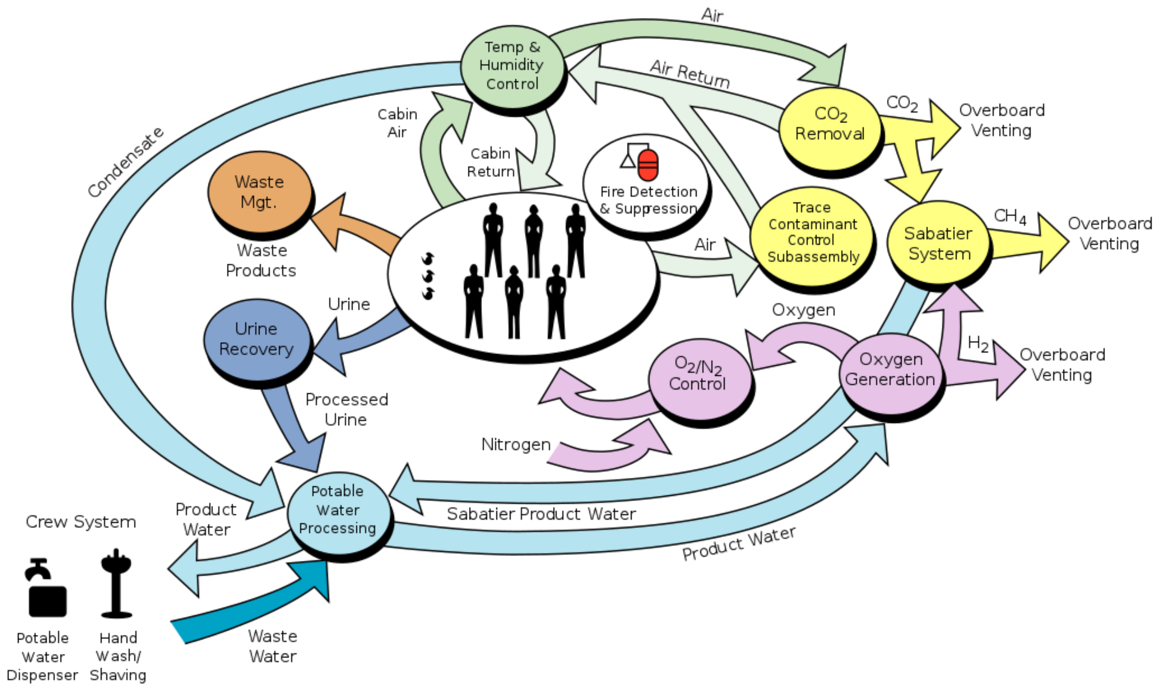
The Sabatier Reaction can be utilised to produce water: The Sabatier Reaction produces water and methane (which in itself can be used as a fuel) from Carbon Dioxide and Hydrogen, both of which can be taken from the moon's soil, atmosphere, etc, or produced from materials found there. The chemical equation for the Sabatier Reaction is:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

This reaction is also exothermic, allowing it to contribute, albeit in small quantities, to the heating of the moon habitat. CH_4 produced is vented into space and the water is pumped into the water recovery system.

Water may be further extracted from the waste products of the astronauts, using NASA's ECLSS (**E**nvironmental **C**ontrol and **L**ife **S**upport **S**ystem), which would comprise of the Water Recovery System (WRS) and the Oxygen Generation System (ORS). The WRS would play a vital role in water reclamation as it will recycle the astronauts' waste materials into clean and safe water for consumption and other use. The OGS produces around 2kg of oxygen per day, and NASA also says that a person will require 0.84kg of oxygen/day to survive and this would mean that a minimum production of 16.8kg of oxygen would be required to support the astronauts, meaning that this system cannot be used to support this many people as demand highly outweighs supply.

The following diagram shows all pathways of waste materials and their product reusage, alongside the processes used to turn these waste products into usable ones. For example, condensation from humidity in the air, byproducts from oxygen generation and urine processing all contribute to the production of potable water for use by the astronauts.



[21]

Whenever supply shuttles are sent to the ISS for example, they will always contain a volume of oxygen which can be received by the ISS and stored in high pressure tanks. This solution would need to be used for the astronauts on the moon, considering the supply is distant from the demand. The addition of extra oxygen from supply vessels would supplement the various oxygen reclamation and generation systems, and it is not very likely that oxygen production will become self-sufficient until a suitable tree farm could be made to recycle carbon dioxide more efficiently. Also, the Solid Oxide Electrolysis of water produces oxygen as a product which is explained below.

Solid Oxide Electrolysis

Solid Oxide Electrolysis is a process which is used to produce Oxygen: Water is electrolysed to produce hydrogen gas and negatively charged oxygen ions. The water for this reaction can simply be taken from the Sabatier Reaction; any excess water produced can be used to create oxygen.
In the long term, an arboretum will be created until it becomes sustainable enough to take over from the methods described above. It is estimated that this will require around 200 trees to comfortably sustain a crew of 20 people. It will be constructed in a large dome of the same design as the rest of the base.

Water Extraction From Regolith Rocks:

To get to the water, microwaves would be shot into the regolith, “thawing” the ice to about minus-50 degrees Celsius. Water vapor would be drawn to the surface by the moon's vacuum environment and then can be collected as ice, which can be thawed again and purified for safe use. It is possible to extract 2 grams of ice from the rock per minute, which has been achieved using a single one-kilowatt microwave. The use of a higher power output microwave emitter, and multiple thereof, could produce a much higher yield of purified water. A nanofiber filter devised to purify water can be used to make the water potable and available for use.

Location Linked to its Properties

An ideal location within the northern hemisphere of the moon, close to the moon's North Pole. It is ideal due to an almost constant exposure to sunlight, though radiation levels would be at a constant high, the fact that solar panels, water heaters etc. require constant sunlight to maintain effectiveness, providing power and a source of heat to the lunar dwellers. Heat from this source could prove vital, as even under the ground in lava tubes the temperature remains a consistent -20 to -25 ℃. Temperatures in the areas of light on the moon can reach 127℃ and on the dark side, temperatures of minus 173℃ can be reached.

With Solar Panels, people understand the basic idea that in the presence of sunlight the photovoltaic cells produce electricity, though they output DC power and require an inverter. For most cases solar power may be effective enough if the number of panels is satisfactory, as the power provided could be reliable for consistent use. A downfall of solar panels is the efficiency and the amount of energy that they provide, which can be rather small compared to other sources, although, in large numbers the solar cells can easily extract enough energy to power the moon base, and also could provide a large amount of energy that can be stored and used at a later date, or be sold into the power grid back on Earth via wireless transmission methods or battery storage and transport.

Peary Crater is seen as an ideal location as it experiences the least time in the shadow of the moon, meaning that it is beneficial in the cases of solar panel usage, as well as temperature variation predictability, where the periods of darkness and sunlight would be considered as a day where the temperatures should be predictable

Compared to another Northerly location, Hinshelwood, Peary crater experiences 79 hours fewer in the shadow of the moon, though it experiences a lower maximum percentage of illumination. This allows for the locations to be compared to one another and Peary Crater would be the most suitable, as the 79 hours less that it spends in the darkness is vital for the conservation of energy in the moon's dark phase, since if solar panels were the main source of energy production then there would be a period where no energy would be produced and energy required would have to come from sources of stored energy The table below applies to the point measured being two metres above the ground, and this is important due to the geography of the moon's surface.

Site	Latitude [°]	Longitude [°]	Max. average illumination [%]	Solar visibility [%]	Max. time in shadow [h]
North pole					
Hinshelwood, H	89.6561	326.34	81.5	89.3	203
Peary, P	89.8521	109.80	77.1	85.06	124

[X] - P. Gläser, J. Oberst, G.A. Neumann, E. Mazarico, E.J. Speyerer, and M.S. Robinson, "Illumination conditions at the lunar poles: Implications for future exploration", *Planetary and Space Science*, 2017. https://doi.org/10.1016/j.pss.2017.07.006

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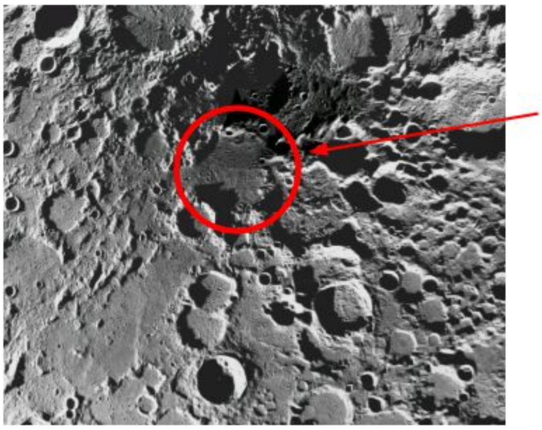
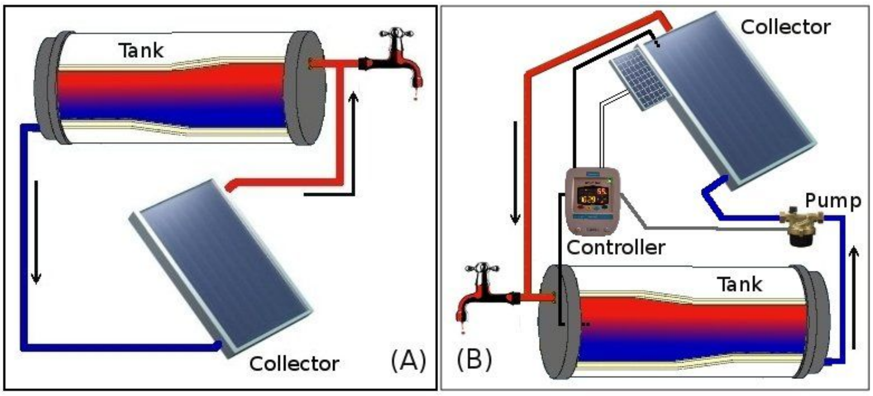


Peary Crater, Circled (General Area) 2019 Imagery, NASA. Google Earth 3D view.

Solar Water Heating / Solar Power

If a habitat was made underground, as suggested in the ideal location section, the temperature will remain a stable -20℃ to -25℃, which is obviously below freezing and therefore dangerous for people to be exposed to for great periods of time, (for risk of hypothermia), so something must be in place to manage the extreme cold.

A solar water heater works on the idea of heat convection, meaning that they manipulate the fact that mediums of a higher temperature rise above mediums of a cooler temperature. The diagram above shows two different systems, A, a simple system and B, a system that features a controller and a pump to create directional flow of the water, for instance if you needed to use the heat to warm an area you would need the water to circulate through pipes or radiators and these systems would need to be supported with conventional pressure systems, due to the lack of gravity.



[3]

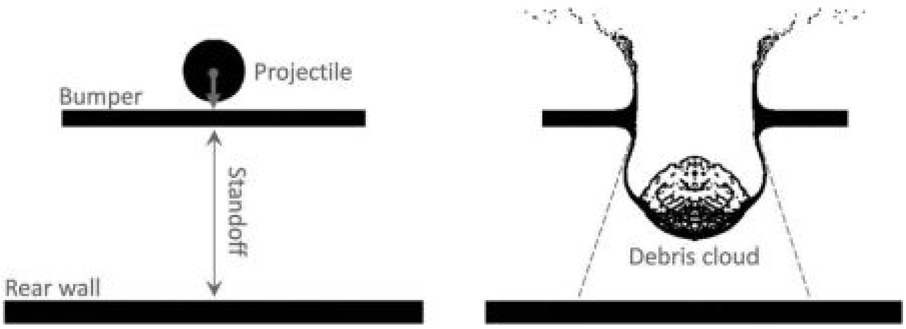
The separation of the red and blue depicts heated water and the cool water respectively. Heated water can be used or heated further using these two setups, with B being a much more controlled and desirable variant for common usage, especially when the water will be used elsewhere, i.e throughout heating systems in our case. Diagram A is a Thermosiphon, described as a passive method of heat collection based solely on the natural convection of fluids and gasses with differing temperatures.

Storage solutions will need to manage the difference in atmospheric pressure, as on Earth we know that water boils at 100℃ at 1 atmosphere of pressure or 101.325 kPa, but on the moon, due to the absence of an atmosphere there is almost 0 atmospheric pressure, meaning that the boiling point of water is significantly reduced. Water would need to be stored at temperatures and pressures reminiscent of Earth for ease of storage as otherwise it cannot exist in a liquid state due to sublimation, which is the immediate change in state from solid to gas, without the liquid state standing between the two, meaning that this is a critical problem when attempting to use water on the moon. Aboard the International Space Station, the internal pressure of the vessels is equal to that of the pressure at sea level on Earth, 101kPa, allowing water to exist as it is below critical temperature and pressure, with only gravity affecting how it behaves.

Space Debris / Lunar Surface Dust

Conventional methods such as whipple shielding are often used on spacecraft orbiting the Earth. Whipple shielding is a method of not stopping, but breaking up and slowing the debris, using a sacrificial metal sheet or plate called a ‘bumper’. The bumper is constantly barraged by debris travelling at speeds from 3 km/s to 18 km/s, and they will frequently be in the path of protected apparatus, therefore requiring something to block the high speed projectiles from colliding with them. The standoff space is usually filled with a material like kevlar, to stop the smaller particles by absorbing residual energy deposited by the projectile.

Figure 4 depicts how a Whipple shield works, on the left of the image is the shield and projectile prior to collision, with the bumper being the sacrificial metal, the standoff being the space between the bumper and the rear wall or object that is being shielded. The space between the two allows for the bumper to stress when it absorbs the energy of the projectile, deforming the metal in the process as well as breaking up the projectile; the deformation of the metal and projectile creates the “debris cloud” where smaller particles exist as a product of the energy transfer - the projectile is pulverized by the extreme change in energy.

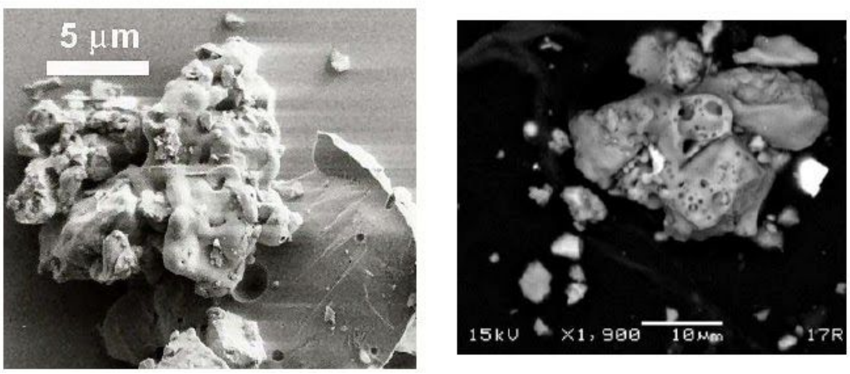


[4]

This is an important device for sensitive items like the moon base itself, as an estimated 500 meteorites collide with the moon’s surface yearly[[5]], suggesting that a high volume of projectiles will reach the surface of the moon and endanger equipment and the location of these strikes is unpredictable. Meteorites are not the only worry however, as moon dust is supposedly heavily “sandpaper-like”, getting this name from its highly abrasive nature:

> “*Dust on the moon behaves a little differently than dust on Earth. For starters, it's sharp. Because there's no wind on the moon, the dust never erodes. Instead, grains of moon dust … remain sharp and abrasive and can easily slice into an astronaut's lung cells if breathed in too deeply.*” - LiveScience [6]

The fact that the dust does not erode poses a threat to sensitive equipment and people that will be on the moon, as in the case of Harrison Schmitt on the Apollo 17 mission, Schmitt inhaled a negligible amount of the dust and ended up with “hay fever-like” symptoms which cleared after a day, though further research on simulated lunar soils depicted the fact that the compounds that make up the lunar soil are actually toxic, attacking human brain cells and lung cells killing 90 percent of them upon contact.[7] In micrographs of the lunar dust, it is evident that the shape of an individual granule is incredibly jagged, relating to the issues faced by astronauts exposed to them.



Scanning Electron Micrograph of lunar dust - NASA, Public Domain, Wikimedia commons. - http://humanresearchroadmap.nasa.gov/Evidence/reports/Lunar%20Dust.pdf

Transport

Overall plan

In order to travel to the moon we will create a system involving shuttles and a form of cable assisted transport.

Shuttles will transport people and materials from the surface of earth to a dock, situated on earth's geostationary orbit (35,785 kilometres above earth's equator). The shuttles will use fuel for travelling during this part of the journey.[[10]]

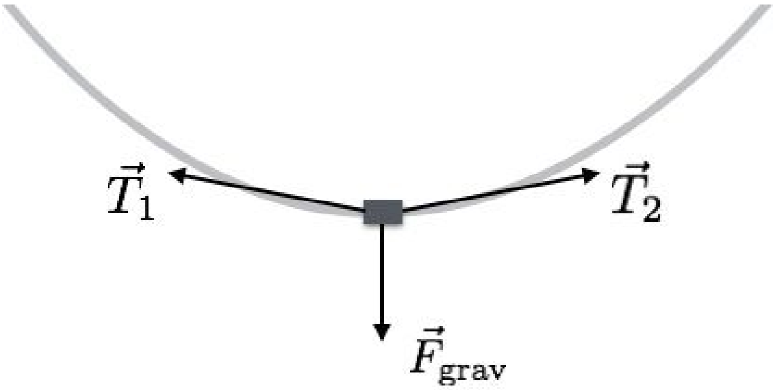
There will be a cable (setup from the geostationary dock to the moon) that then transports the shuttles to the moon. Once the shuttles have completed the trip from earth to the geostationary orbit they will be connected to the cable in order to travel to the moon.

Using a space cable in order to travel to and from the moon is a lot more efficient and cost effective than using a shuttle for the trip. The space cable requires less fuel, costs less in shuttle maintenance (shuttles can be reused), can carry heavier loads, and travel faster than a shuttle making the same journey. We have made the decision to use a geostationary dock to assist the cable as creating a full space elevator (directly from earth to the moon) is physically impossible due to the atmosphere and current technology. [[11]]

The cable will contain powerful permanent magnets that prevent the shuttles from touching the cable (as this would eventually lead to the wearing down of the cable) and reduce the strain inflicted on the cable. The shuttles moving along the cable will be powered by solar panels, situated on each shuttle. The shuttles will mostly power themselves, eliminating the need for stations along the cable for the shuttles to obtain more power. The use of solar panels at the geostationary dock will also give the shuttles enough power to travel from geostationary orbit, back to earth. The shuttles will have enough fuel to power themselves towards the geostationary orbit, as they produce solar energy.

As many shuttles as required can travel on the wire at one time -as each shuttle causes negligible strain on the wire (due to the use of permanent magnets). However there must only be shuttles travelling on the wire in one direction at all times, shuttles needing to go in the opposite direction must queue at one end.

The cable will be kept taut due to the forces it experiences at either end, being larger than the force felt on the cable as the shuttle moves (see below).



[12]

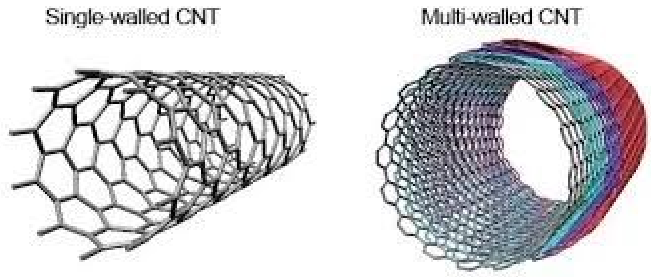
Engineering a suitable cable

Cable purpose
The purpose of our cable is to transfer shuttles from the dock in earth's geostationary orbit. The cable is required to be strong, durable and flexible enough to support the transport of small shuttles and their contents from the dock to the moon. The cable will hold strong electromagnets, which will work to secure the shuttle to the wire-acting as an extra safety precaution as well as a method of power the movement of the shuttles more efficiently.

Cable type
The cable will be a structural cable, capable of carrying current (in order to power electromagnets) due to the type of material used to create it. [13]

Cable material
A cable developed from carbon nanotubes.A carbon nanotube is composed of a single layer of carbon atoms in a cylindrical configuration. It is possible for the tubes

to be multiwalled (see below) or single-walled.



[14]

We will use multiwalled carbon nanotubes to manufacture our cable as they are stronger than single walled nanotubes. Multiwalled carbon nanotubes are also less expensive than single walled carbon nanotubes. This means that the cable will be cheaper to build, rather than if it was built with single walled carbon nanotubes.

We have decided to use nanotubes as they are notorious for being extremely flexible and elastic (<18% elongation to failure, with a Young's Modulus 5x more than that of steel), and therefore have a high tensile strength. They also have a low thermal expansion coefficient. Nanotubes are approximately 50 000 times smaller than the width of a human hair, due to this factor we can engineer extremely sturdy cables out of many multiwalled nanotubes.[15]Carbon nanotubes can be constructed with a length:diameter ratio of up to 132,000,000 : 1. [16]

Carbon nanotubes are also capable of carrying four times the amount of current compared to copper, this will also benefit us as we will have electromagnets within the cable. A low thermal expansion coefficient means that the thermal energy produced by an increased current will not be detrimental to the structure of the nanotube cable.

Carbon nanotubes can be cost effective or costly. The cost of the "economy class" nanotubes is up to £200 per kilogram, however these tubes tend to have larger diameters and worse properties. The cost of "first class" nanotubes is up to around £90,000 per kilogram, these nanotubes are usually single walled with the very best properties. We suggest the use of "first class" nanotubes in order to create the most long lasting and efficient solution possible.[17]

Carbon nanotubes fibers can also be made into conductive tapes, these can be used to support supplies being transported in the shuttles.[18]

Cable setup

The cable will need to be 342236km in length. Due to the incredibly lightweight and flexible nature of the tubes, we are capable of setting up the cable in large chunks. The cable is capable of being rolled up- to be unravelled again at the location. The rolled up cable will be taken to the destination (moon dock) by shuttle and will be unravelled outwards from there, back towards the geostationary dock.

The cable will still need to be taken up in multiple parts, however the fact we can make the cable more compact- transporting the setting up the cable will be simpler and more cost effective. Parts will need a small amount of assembly required as they are taken up and connected- the first piece will connect to the moon dock, and the last piece will be fastened to the geostationary dock.

Transport strategy

Each shuttle will take around 8 hours to travel to the moon, then 8 hours back. If we give 4 hours to unload the materials, each full transit will take around 52 hours to complete. To build the moon domes and airlocks alone, it will take around 39 days to transfer all materials to the moon..

In order to build the base we will be required to transport materials, tools and equipment to the moon. The moon base needs digging tools, such as diggers and jackhammers, to dig the soil and rock underneath the base. The moon base will also be used for scientific experimentation and farming so some pieces of large machinery will be needed. For these these larger items, they will be dismantled in order to be transported then rebuilt by mechanics when they reach the moon.

The diameter of each dome will be 10m, therefore the surface area of each dome will be approximately $157m^2$. The polymer will be taken to the moon in sheets to be assembled into the dome, on the moon. Each dome will require two shuttle trips to carry the polymer sheets to the moon.

The air locks will be built from metals, such as steel. Steel is much heavier than the polymer material, however the air locks require much less.

The volume of fuel taken by the shuttles (in order to travel to the geostationary orbit) will differ depending on the weight of their load.

The use of a space cable will enable the shuttles to be transported to and from the moon on a regular basis, the shuttles will have a schedule based off the time it takes them to reach each destination (around 8 hours each way).

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