The Creation and Logistics of a Lunar Base

An Interactive Qualifying Project Report completed in partial fulfillment of the Bachelor of Science degree at Worcester Polytechnic Institute

By:
Abraham Hirwa
Matthew Nagy
Christopher Ritter

Submitted to:
Worcester Polytechnic Institute
Professor Mayer Humi

Date:
July 20, 2020

Abstract

As humanity continues to grow, the idea of expanding beyond Earth becomes more appealing. There are commercial and practical reasons to harvest the Moon's resources, such as He-3, a cleaner fuel source, as well as setting up the Moon as a building block for further space exploration. This project explored the problems and possible solutions as we need to nourish and protect astronauts from the Moon's harsh environment and to transform it into a more suitable place for life.

Table of Contents

Executive Summary

As humanity seeks to expand beyond Earth's boundaries, the Moon represents a great starting point. The Moon has resources such as titanium, helium-3, iron and aluminum. The problem would be extracting these resources from the Moon. This extraction would need highly advanced and new technologies such as robots adaptable to the Moon environment. However, even if the extraction issue was resolved, transportation of these resources back to Earth in the long run would be much more complicated without a stable base on the Moon. A solution would be to establish a base on the Moon.

A Moon base would provide better space travel by having a railgun built on the Moon and also the access to Helium-3 on the Moon which would be used to create rocket fuel. The ability to have railguns and fuel on the moon allows for space transport to be more efficient as rockets going on long scale missions from Earth can refuel on the Moon and use it as a secondary launching point since the majority of fuel used is from the rocket breaking Earth's atmosphere. A problem humanity currently faces is identifying asteroid threats to Earth and the Moon, a Moon base would serve to monitor for these asteroids and track their trajectories. By having a base set up on the Moon, we could build telescopes in the colony to identify these threats; should these asteroids show an apocalyptic threat a missile system could be used to avert these threats by changing the trajectories of the incoming asteroids.

An issue with a space colony is that it needs to be protected and self sufficient in order to succeed. To solve this, firstly, the base would need to be built underground as radiation and debris is more common on the surface, since the Moon has no magnetic field or atmosphere to

protect itself, like the Earth does. An underground base can utilize a developing greenhouse that is almost 100% self sufficient for an astronaut, needing only supplemental salts sent to space on a yearly basis, allowing for numerous greenhouses to be built to support life on the Moon. Having access to resources would require prior planning for where the base is set up. Having the base near the northern pole would allow for the most direct amount of sunlight and get the highest use out of solar panels. The Moon also has ice near the northern pole that can be mined to make water for drinking or fuel purposes. Radiation is another threat to life in space that people must work around. Currently, a life form known as a Tardigrade can be a key for learning how to protect cellular DNA from destructive ionizing radiation. Tardigrades being able to reinforce and protect their DNA could hold the answer to strengthening colonists bodies to combat the exposure to space radiation. Low gravity is detrimental to the human body and can cause it to weaken as most muscles are not under stress or used in low gravity. This issue is alleviated by specialized exercises that simulate what gravity is like on Earth. Astronauts need to stay in shape for when they come back to Earth, otherwise their bodies are too weak and fragile for Earth's gravity. Exercise machines are used currently but more are being developed to be more effective.

Having a self-sufficient base set up can help the Earth as well, such as setting up mirror panels in the sky that can be used to power solar panel plants on Earth to give them power even when there is no sunlight. Having mirrors set up orbiting Earth could also be used for agriculture and while solar energy helps, other forms of energy such as Helium-3 for fusion reactors is important, but also tidal energy, since the Earth is slightly more than 70% water. More stations can be set up to take advantage of the kinetic force of currents to create power for the world.

The other benefit of having Helium-3 from the Moon and the other previously mentioned sources of energy is that these sources of energy are significantly cleaner and better for the environment than using fossil fuels. Once the technology for Helium-3 fusion reactors can support power on a large scale, it would help eliminate the need for burning fossil fuels. Currently 80% of the world's energy comes from burning fossil fuels and almost eliminating most of that carbon footprint would help combat global warming. Clean forms of energy help the Earth in the long term from drastically changing its climate.

Why Lunar Base?

As humanity continues to advance the next step in humanities development is to construct bases and outpost off of the Earth. The most logical location for the first off world base is the Moon. The Moon is the ideal location for a human base that is not on the Earth; the Moon is easily accessible, it has possible commercial development, access to minerals and elements which are rare on Earth, the ability to advance scientific knowledge, and act as a starting point for future space missions to more distant places within the solar system.

Easy Access

One of the main aspects of the Moon that would support a base is that we already have managed to get manned missions to the Moon and land on it. For any base to be built off of Earth it is necessary for it to be within range for us to access it with minimum risk, it is because of this that the Moon would create an ideal location for an off world base. For a spacecraft to get from the Earth to the Moon it takes from 2-5 days, the most dangerous aspect of any space mission would be the time spent traveling through space so this short period of time allows for a mission to be sent with minimal risk. Another benefit of the Moon being close to Earth is that re-supplies would be able to get from the Earth to the Moon quickly and efficiently.

Commercial Interest

The construction of a lunar base also comes with a number of commercial interests ranging from gathering resources, the advancement of science and space tourism; these commercial interests are some of the primary causes to build any base off of Earth.

The four of the most abundant materials on the lunar surface are titanium, aluminium, calcium, and iron. Titanium on the Moon exists primarily as ilmenite ($FeTiO_3$), ilmenite on the Moon captures hydrogen so as this mineral is processed this hydrogen is released and can be collected; this ilmenite can be broken down to pure titanium which can be used in a number of military aircraft and spacecraft. Iron on the Moon can be found in ilmenite, magnesium iron silicate (Fe_2SiO_4), and small trace amounts of pure iron. Aluminium can be found on the Moon in anorthine ($Ca(Al_2Si_2O_8)$) which tends to be about 20% aluminium, the aluminium can be easily extracted from this mineral in large quantities as it is processed. Calcium can also be extracted from anorthine, calcium metal is a very good electrical conductor but is not used on Earth due to its reactivity with oxygen, in space it would be possible to use calcium as a conductor without worrying about its reactivity. On the Moon there are also large amounts of Helium-3 which could serve as a possible source of fuel for nuclear fusion.

In terms of scientific advancement a lunar base offers many benefits; these include viewing the long term effects of low gravity on the human body, the construction of space telescopes, an off world seed vault, and a spaceport. From the international space station we see that low and zero gravity have a negative impact on the human body, with a lunar base it would be possible to the impact of low gravity and figure out how to avoid these issues. Building space telescopes on the Moon would allow for viewing of both Earth and space without too much interference. Currently on Earth there exists the Svalbard Global Seed Vault in Spitsbergen Norway, this seed vault is intended to secure a genetic diversity within plants should there be a global catastrophe, should another of these vaults be built on the lunar surface it would act as another back up in the situation where the Svalbard Vault becomes inaccessible. A lunar spaceport would serve as a gateway to future space missions to locations such as Mars; the topic of a lunar spaceport will be discussed in greater detail later in this paper.

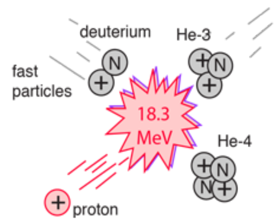
One of the more distant outcomes of a lunar base will be space tourism. With companies such as Virgin Galactic who are already selling tickets to space show that the interest among civilians is present (even if currently only the ultra-wealthy would be able to afford these tickets). As the technology becomes more advanced and a lunar base is up and running the next natural step would be tourism and allowing those who wish to travel off of this planet to have that option. Companies like Blue Origin are selling tickets just to get into space cost in the range of 200,000-300,000$, while Virgin Galactic is also selling tickets for 250,000$; should the technology for rockets become cheaper and more easily reusable over time, space tourism shows that it has the possibility to be an incredibly lucrative business.

Helium-3 Mining

Helium-3 (He3) is a stable Helium isotope with two protons and one neutron. This isotope is non-radioactive which makes it a safe fuel source for nuclear fusion reactors.Unlike nuclear fission reactors, fusion reactions do not produce runaway chain reactions as in fission. Additionally, fusion reactors do not produce large amounts of dangerous radioactive wastes which are bad for humans and the environment. Therefore, a possibility for He3 fusion reactors would make a cleaner and more efficient source of energy than the current fission and carbon fuels being used; with radioactive and nuclear harmful byproducts. The process of He3 fusion is to fuse Helium-3 and Deuterium(Hydrogen-2) to create a Helium-4 atom and a high energy proton, this high energy proton is then used to heat water to the point it becomes steam which then powers a turbine creating electricity. This reaction is

$$ {}^{2}_{1}H + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + 18.3MeV $$

Deuterium-helium-3 Fusion



On Earth He3 is very rare and found only in small quantities, however on the Moon He3 is much more readily available due to the lack of atmosphere interfering with solar winds, these solar winds hit the surface of the Moon and deposit the He3 and other elements, the concentration of He3 on the Moon is between 20 and 30 ppb. As various countries, such as the United States, plan to establish outposts and/or bases on the Moon within the next decade it is not out of the realm of reason for these bases to act as a cornerstone of a mining operation to collect and process the He3. In order for a substantial mining process to take place there would have to be large robotic vehicles (similar to a self driving tank) to sweep and dig into the surface of the Moon to collect the He3.

The current state of the use of He3 is that there is a proof of concept small scale He3 fusion reactor that shows that the technology is possible; however there is currently no large scale commercial fusion reactor and they might remain multiple decades away; this is due to the majority of current research into fusion being based around Deuterium-Tritium (Hydrogen

2-Hydrogen 3) reactions, when fused create a Helium-4 atom and a high energy neutron, this high energy neutron is highly destructive and difficult to utilize the full energy it releases. Once fusion is achieved it would release large amounts of thermal pollution which would have effects on the environment should it be done on Earth; this thermal pollution is the largest drawback to the use of the He3 in fusion reactors. While He3 is much safer than Hydrogen as a fuel source for fusion reactors, very little radiation and radioactive material, the thermal pollution and effect on bodies of water can be found to increase the temperatures of them by 1.5°C, using the Danube River in Romania as an example, which will affect wildlife in the local area; this thermal pollution would be slightly lessened by the fact that there would be less carbon pollution produced by fossil fuels, this lack of carbon pollution would allow for more of the thermal pollution to escape from the atmosphere.

There are three options in terms of dealing with this thermal pollution. The first is just to accept the pollution and go through with the fusion while on earth; this allows for easy access to the energy created but also could increase the effects of climate change and the He3 must be transferred from the Moon to Earth, with about one 25 metric ton shuttle load of He3 being estimated to power the US for one year. Most current greenhouse gasses, about 32% of them in the US during 2018 were from electricity, and 7% from non-fossil fuel combustion. Switching fossil fuel based plants and non Helium-3 plants would significantly cut down on emissions and would result in lower greenhouse gas pollution, with the drawback of possible thermal water pollution. The second is to go through the fusion process while on the surface of the Moon and then somehow transfer the energy that is created back to Earth, this would decrease the effects it would have on the climate as the Earth is not subject to the thermal pollution but the process of transferring the energy back to Earth would be difficult; some possible methods of transference would be the use of large batteries to store and transport the energy which would need large amounts of materials and require shuttles to bring them to and from Earth. Another option is a type of laser to transfer the energy which would dissipate as it gets farther from the source. The third is to create a space station such as the ISS and go through the process of fusion while on that station and then transfer the energy back to Earth; this carries the same benefits and downfalls of going through the process on the Moon but this would be closer to Earth allowing a laser to be more efficient when transferring the energy.

Space Telescope

One possible use of the lunar outpost is to work in conjunction with a lunar telescope which could be built to scan space for near Earth objects such as meteors which could either be dangerous to life on Earth or carry with them rare elements. There are two types of telescope which would be of interest to build on the lunar surface: the first being a large liquid mirror telescope and the second being a radio telescope.

Liquid mirror telescopes consist of a horizontal vessel filled with a shallow liquid with the most common liquid being mercury; this vessel is then spun at a low speed, the inertia of the spinning vessel pushes the liquid to the outer edge while gravity acting on the liquid pulls down on its surface. The inertia and gravity acting on this liquid creates a perfect parabola which acts as the reflecting surface of the telescope. Liquid mirror telescopes must be kept at the horizontal or the liquid would pour from the vessel and the parabola would be broken. The best place for a liquid mirror telescope to be built on the lunar surface is in one of the many craters at the lunar poles. Having the telescope at the poles would allow for the viewing of space with minimal visual interference from the Earth, also this leaves room for solar panels to be built in the most efficient location. The craters at the lunar poles are permanently in shadow keeping the temperature -238°C to -247°C, this low temperature allows for the ideal conditions for infrared astronomy. Due to the liquid mirror telescope being in a fixed position it does not require the equipment to rotate the mirror and also decreases the overall weight of the telescope, this makes it possible for all the materials of a 20-meter telescope to be transported from the Earth to the Moon in a single shuttle launch. Figure 1 shows a possible build for a liquid telescope outlined by Poels of the International Liquid Mirror Telescope Project.

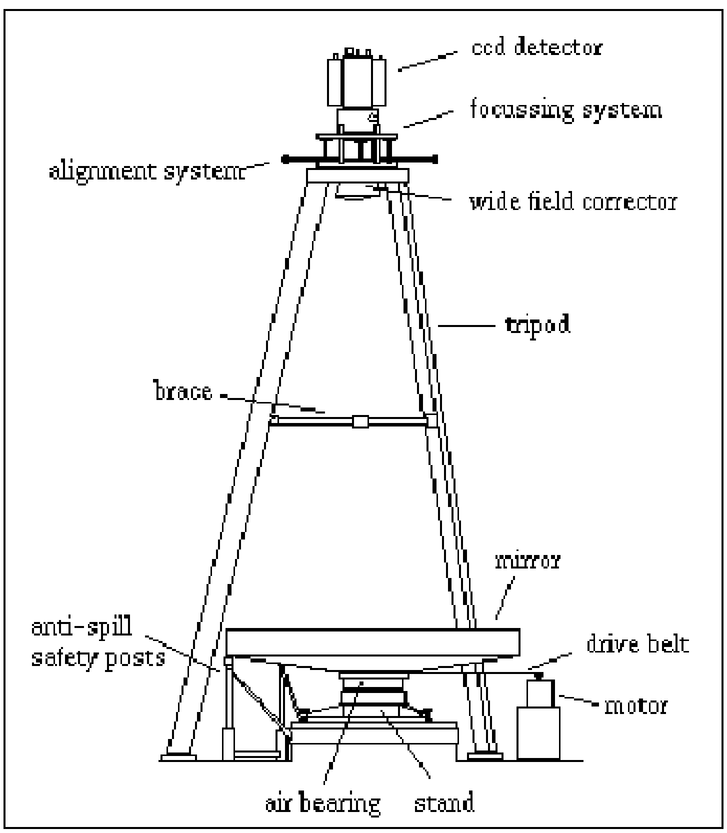


Figure 1: "Entire liquid mirror telescope system." (Poels et.al., 2001)

Radio telescopes consist of a large parabolic disk in which the astronomical radio waves are bounced off and focused into a central antenna. Radio telescopes have been used on Earth for many years but due to the ionosphere we have been unable to examine frequencies below 30MHz, building this telescope on the Moon would allow us to gather and view these lower frequencies. Similar to liquid mirror telescopes it would be best to build this radio telescope in a large polar crater which would act as a natural barrier blocking background noise from Earth based sources and the radio noise which comes from the Sun. Due to the large size of some of the lunar craters it is possible to build a radio telescope upwards of 1km which would allow for the collection and viewing of frequencies in the range of 6-30MHz. Figure 2 shows "Schematic diagram of the Parkes Telescope", the Parkes Telescope is a 64 m radio telescope commissioned by NASA in 1961, a design similar to this could be used on the Moon and greatly scaled for the lunar radio telescope

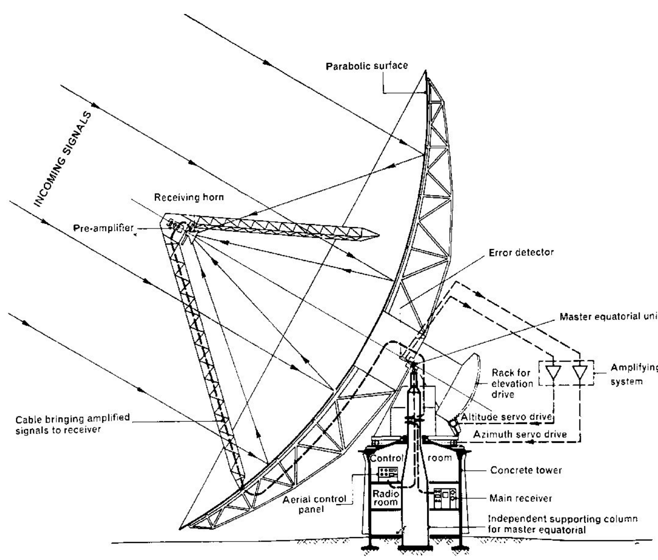


Figure 2 : "Schematic diagram of the Parkes Telescope" (Sarkissian)

Due to the influx of lunar craters it is possible to build both liquid mirror telescopes and radio telescopes on the lunar surface, these telescopes would allow for greater scientific discovery. Due to liquid mirror telescopes being stationary they are best used to observe large numbers of galaxies and supernovas (with an estimated 8m telescope being able to view over 1 billion galaxies), this would allow for astronomers to better determine some of the effects of dark matter on the spread of the universe. For radio telescopes the astronomical radio frequency range of 6-30MHz is nearly uncharted territory due to our inability to properly measure them while on Earth, once we build a radio telescope on the Moon we will be able to view these range and start to make more discoveries around them such viewing a greater range of frequency being produced by stars and black holes.

Spaceport

When launching a rocket or other spacecraft the most fuel cost comes from leaving Earth’s atmosphere, with fuel cost ranging from 96% per total rocket mass (for solid rocket fuel) to 83% per total rocket mass (for Hydrogen-Oxygen fuel). Due to this large cost of fuel per mass long distance missions from Earth have only been able to carry a limited amount of hardware on these missions. To counter this cost it is possible to build a spaceport on the Moon in order to act as a halfway point for missions leaving Earth; one use of this port would be to refuel any rocket which lands there, the other use of this port would be to launch a rocket to further locations. A possible method to launch the rocket would be a large electromagnetic railgun.

An electromagnetic railgun is a method of firing projectiles using electromagnetic currents. An electromagnetic railgun consists of two parallel rails, a sled attached to a sliding metal conductor, and whatever projectile is being fired which rests on top of the sled. To fire the projectile large electrical currents pass through the railgun rails, these currents produce opposite magnetic fields in the rails, in turn these magnetic fields force the sliding metal conductor forward, once the conductor and sled reach the end of the rails they are stopped while the projectile continues on and is launched. Current railguns on Earth can launch 23lbs projectiles at 4500-5600mph; on the Moon this same railgun would be able to launch a projectile close to 138lbs due to the lower gravity. The escape velocity of the Moon is 2.38km/s (approximately 5323mph) which means that a railgun on the Moon would need to be able to launch at this speed which is in the current possible range. Current railguns are mounted on large ships which only allow for the railguns to be so large, once these railguns are on the Moon they can be built much larger and provide more room for the projectile to accelerate.

One of the primary forces that contribute to the function of railguns is the Lorentz Force. The Lorentz Force is a combination of electric and magnetic forces acting on a charged point. The Lorentz Force can be derived as

$$F=q\mathbf{E} + q\mathbf{v} \times \mathbf{B} \qquad (1)$$

In equation (1) the bold values are all vectors, q is the charge of the particle which passes through the system, E is the present electric field, v is the velocity of the particle and B is the magnetic field. From this equation we see that the force must be perpendicular to both the velocity and the magnetic field. This Lorentz Force is the force which drives the sled of the railgun.

Should a lunar base/outpost be established it would be possible to build a large electromagnetic railgun which would be able to launch rockets from the Moon deeper into space; currently railguns have been proven to work and have been developed by the US Navy, but these railguns only fire a 23lbs projectile compared to the multi-ton rockets that would be fired from the space port. In order for a railgun to work as a launch system from the Moon we would have to significantly increase the current size of the railguns we have built.

One possible future mission from the Earth to Mars could consist of a rocket using rocket fuel to leave the Earth's surface and then orbit the Moon, at this point the rocket would resupply with any additional materials for the trip to Mars and extra fuel, after this resupply the rocket would use the on board fuel to proceed to Mars. A second possible mission is for the rocket to actually be built on the Moon where it would load up on resources for the trip and then be launched by the railgun in a trajectory to Mars where it would use the on board fuel to adjust the trajectory as it nears Mars.

An alternate form of rocket propulsion is ion propulsion. Ion thrusters work by ionizing propellant, this ionization is done by shooting a high-energy electron at the propellant atom, this causes the propellant atom to release electrons; the combination of the positive propellant ion and the negative electron results in no net total electrical charge. This positive ion and negative electron exist as plasma within this ion thruster. The electrons in the ion thruster are produced by a hollow discharge cathode, these electrons are attracted to the positively charged walls of the discharge chamber, the positive charged walls are created by applying a steady voltage through the walls. After the production of these electrons, neutral propellant is released into the discharge chamber, these electrons then are shot into the propellant to create the desired positive ion and release more electrons. To increase the chance that ionization occurs, strong magnets are used on the free electrons to stop them from reaching the walls of the discharge chamber. These ions and electrons are separated by a positively charged electrode which attracts the electrons. A high voltage is then applied to the chamber forcing the ions out of the thruster as a beam. For the spacecraft to retain a net neutral charge, electrons are also released from a neutralizer which releases an equal number of electrons. The most common propellant is xenon because it is easily ionized and has a high atomic mass providing greater momentum. These ion thrusters are capable of reaching speeds of 90km/s.

Needs of Lunar Base

For any human base to survive off of Earth it requires certain resources so that the inhabitants do not die off. The first of these requirements is enough food for all the inhabitants to survive. The second of these requirements is access to water in either liquid or ice form. The third requirement is access to energy needed to power life support systems and other base functions. The fourth requirement is a capable crew to monitor and run the base. The fifth and final requirement is a safe location to construct the base in an area where all other requirements can be met.

Food

For a human colonization to last on the Moon, the establishment must be self-sufficient when it comes to food and water, since having to have food delivered regularly from Earth to the Moon would not be sustainable cost wise having to send rockets on a regular basis to send food. Considering that an average mission has about 3.8 pounds of food, including about 1 pound of packaging, per astronaut per day, that would equal, for 5 astronauts being sent into space for 1 year, over 5 tons of food, 5,035 pounds of food not including any extras just in case. A larger colonization would make it unreasonable to send that much food that often into space to sustain the colonization, where one rocket could cost upwards of 2 billion dollars, not accounting for how much food is on the ship or how many rockets would need to be sent to sustain the colonization, so alternative methods must be found.

What would be a better solution is if somehow the colonization could grow its own food. One solution would be a greenhouse on the Moon so that food can be grown and provide oxygen for astronauts. The design of a current model for a collapsible greenhouse is aiming to be self-sufficient and must hit as close to 0 waste as possible. Carbon Dioxide from humans exhaling would allow the plants to create Oxygen and humid air in the greenhouse waters the plants and allows for water to be drinkable for the astronaut as well. Right now, the robotic garden needs a few pounds of replacement nutrient salts each year to supplement the astronauts, but that still requires support. The greenhouse would only need 1 astronaut for it to have its 1-year sustainability before it would need its replacement salts for the astronaut.

Figure 3 : Design of the greenhouses (Cody Sheehy)

The technology would need to finally hit 100% self-sufficiency in order to be a viable choice for a space colonization, since at its current state, yearly shuttle trips for supplies defeats the purpose of them trying to be self-sufficient.

Water

While the portable greenhouse idea, previously stated in the Food section, would allow for water to be part of the self-sufficient process, more water is available on the Moon in case it is ever needed. Within the rocks of the Moon on the surface, there is frozen water, which can be mined by robots. These groupings of ice can be extracted and melted into water. There is also another use for this water, and that would be to make rocket fuel, since oxygen and hydrogen are the main materials in powering rockets. Hydrogen can also be mined for as well, for similar reasons, since the greenhouses would produce its own oxygen that mining for hydrogen can also create more water and/or rocket fuel. One issue with the robots that would do the mining, however, is that it is extremely costly, and possibly not necessary cost wise. It is predicted that if the robots are used for just trying to gather resources for making fuel, that it would take a decade for the mining robots to be more profitable, but mining on the Moon is still a risky endeavor. Having a colonization on the Moon could allow for repairs on the robot in case of malfunction or damage, Which would require humans to make the repairs by either the astronauts going to retrieve the robots, or themselves going to the location of the broken down robot and making repairs there, the first idea being more realistic and practical. As for water safe to drink, having to purify the water from mining after creating or mining for it still may not be necessary because of the greenhouses.

Energy

For an outpost to be established on the lunar surface, it is a necessity to have a stable source of energy to power that outpost, with the most convenient method of producing electricity would be through solar energy. Much like on Earth, different locations on the Moon receive different amounts of sunlight with the Northern and Southern poles (85° to 90° North or South latitude) having the highest concentration of sunlight; the Northern pole is in sunlight 89% of the year (approximately 324 days) while the Southern pole is in sunlight 86% of the year (approximately 314 days). In addition to the poles, the areas at the rims of craters are in sunlight 80% of the year, while some areas such as the depths of craters are never exposed to the sun. Due to having the highest concentration of sunlight, the lunar poles would be the most efficient location to collect solar energy with the absolute most efficient location being the Northern pole. Using solar panels of a similar efficiency to the International Space Station (approximately

14%), the panels would have to take up 2500 m^2; as more efficient solar panels are used the needed area for the solar panels would be significantly decreased.

The main danger that will face the solar panels are radiation and damage from small particles of space junk. One method to protect the solar panels from radiation is to cover the panels with thin sheets of fused silica(such as Corning's 7980) which has a high resistance to radiation darkening. Possible methods to protect the solar panels from space junk is to cover the panels with a sheet of polycarbonate or a sheet of acrylic; polycarbonate can transmit light up to 89% and has a high impact strength of 35 kJ/m^2 but is prone to turning yellow under UV light requiring the sheets to be replaced, acrylic can transmit light up to 92% and is not affected by UV light but only has an impact strength of 15 kJ/m^2. Due to their properties, acrylic would be a far better option to use as a guard for the solar panels as it can transmit more light than polycarbonate and does not yellow over time, however the one drawback is that it is more likely to suffer failure when faced with a heavy impact. There is currently no way to protect the panels from large meteor strikes which would be able to wipe out the panels even if they are protected by the more resistant polycarbonate, because of this it would be necessary to invest in a way to destroy or re-route the meteors before they are able to strike the area of the outpost. Overall, the best method for collecting solar energy while on the lunar surface would be to build solar panels at either of the lunar poles as they spend the most time in sunlight, use a thin coat of fused silica to protect the panels from degradation due to radiation, and use a layer of acrylic over the panels to protect from damaging the panels due to space debris; it is also beneficial to develop a missile system around the outpost to use against meteors which could hit the outpost or the solar panels.

During the day these solar panels would be used to power the station but the majority of the power they produced would be stored in batteries for the night and any emergency situations.

Due to the possibility of the solar panels being knocked out by an asteroid or meteor or any other catastrophe, it is necessary to have a secondary means of producing energy for these possible emergencies. One possible solution to this is to have a generator stationed in the base, this generator would run off traditional fuel sources and need to be supplied with enough fuel to last until a team can fix the solar panels. Another possible backup power supply would be to build a He3 fusion reactor on the Moon to power the base, due to the easy access of He3 on the Moon this would be a long term backup supply for power; an alternative to this He3 fusion reactor would be a traditional small nuclear reactor which would be used in these emergency situations.

Crew

In order for a group of colonists sent to the Moon to set up a base, firstly there must be a selection process to who would be sent into space. A good starting point would be to use NASA's own selection process in how they pick astronauts. Firstly, candidates for being an astronaut for NASA must have at least a bachelor's degree for engineering, biological science, physical science, or mathematics. A team of colonists that have enough people to cover these bases would strengthen the team by making it more versatile, having a group of individuals who can have at least one person specialized in an issue the team may encounter. Not on the NASA list but would be helpful to ensure and train the crew members on growing and caring for plants as the greenhouse would be the primary food supply for the colony. NASA also requires on top of the bachelor degree at least 3 years of professional experience or at least 1,000 hours of piloting a jet aircraft while being in command. The years of experience can be substituted according to NASA's requirements by getting a master's degree corresponds to 1 year of experience and a doctoral degree corresponds to 3 years of experience.

Before the formal training, another basic requirement is needed for NASA astronauts, a physical. Astronauts at NASA must have vision that can be corrected to 20/20 in each eye, blood pressure cannot exceed 140/90 while being measured in a sitting position and the astronaut cannot be any shorter than 62 inches but not any taller than 75 inches. Once a person meets these requirements they must go through numerous forms of training. At NASA, they must be SCUBA qualified to prepare them for spacewalking. They must also do a few swimming tests with and without a suit on and tread water for at least 10 minutes. The astronauts are then exposed to high and low atmospheric pressures and 40 times a day experience weightlessness in a modified jet aircraft for about 20 seconds to help prepare the person for the experience of space. They are then trained on using the spacecraft systems and experience the weightlessness of space flight.

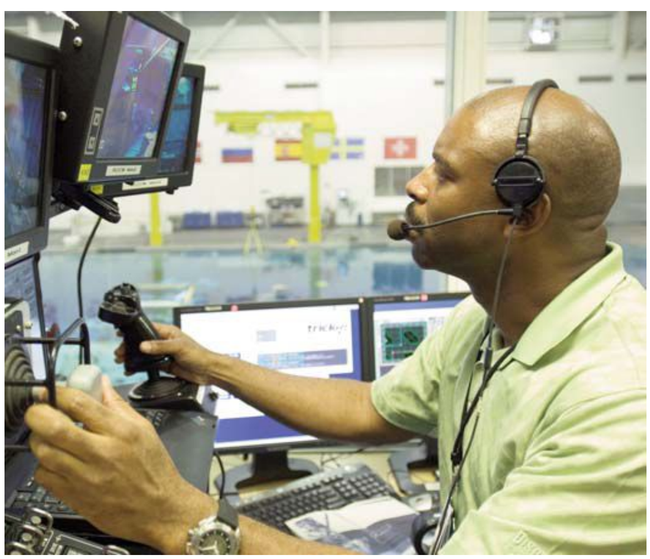


Figure 4 : Flight training simulator (NASA)

The base training and requirements for becoming a NASA astronaut as well as having the crew be familiar and skilled with robotics will ensure a strong group that would have the knowledge to overcome challenges and build up the colony on the Moon.

Location

When considering the location to build a lunar outpost it is necessary to consider three things; how the consistency of the environment around the outpost, how those living in the outpost would get water, and how the outpost would be powered. The environment on the Moon can greatly vary in different locations on the surface, with daytime temperatures reaching 127°C and nighttime temperature of -173°C, because of these large fluctuations any structure would undergo large pressure changes as time goes on. There are two primary solutions to the changes in environment; building the outpost in craters caused by meteor or building the outpost in un-collapsed lava tubes. Currently there are multiple craters that could serve as a possible location for an outpost but currently the only lava tubes found are collapsed and unable to be used for the purposes of building an outpost.

One of the more possible spots to build a lunar outpost is just under the rim of the Peary crater which is an approximately 73 km wide crater near the lunar North pole, it is estimated that the temperature near the rim of the crater is consistently around -50°C. The below temperature map (figure 5) shows the temperature variation at the lunar North pole as found by NASA's

Lunar Reconnaissance Orbiter which first started observing the lunar surface in 2009.

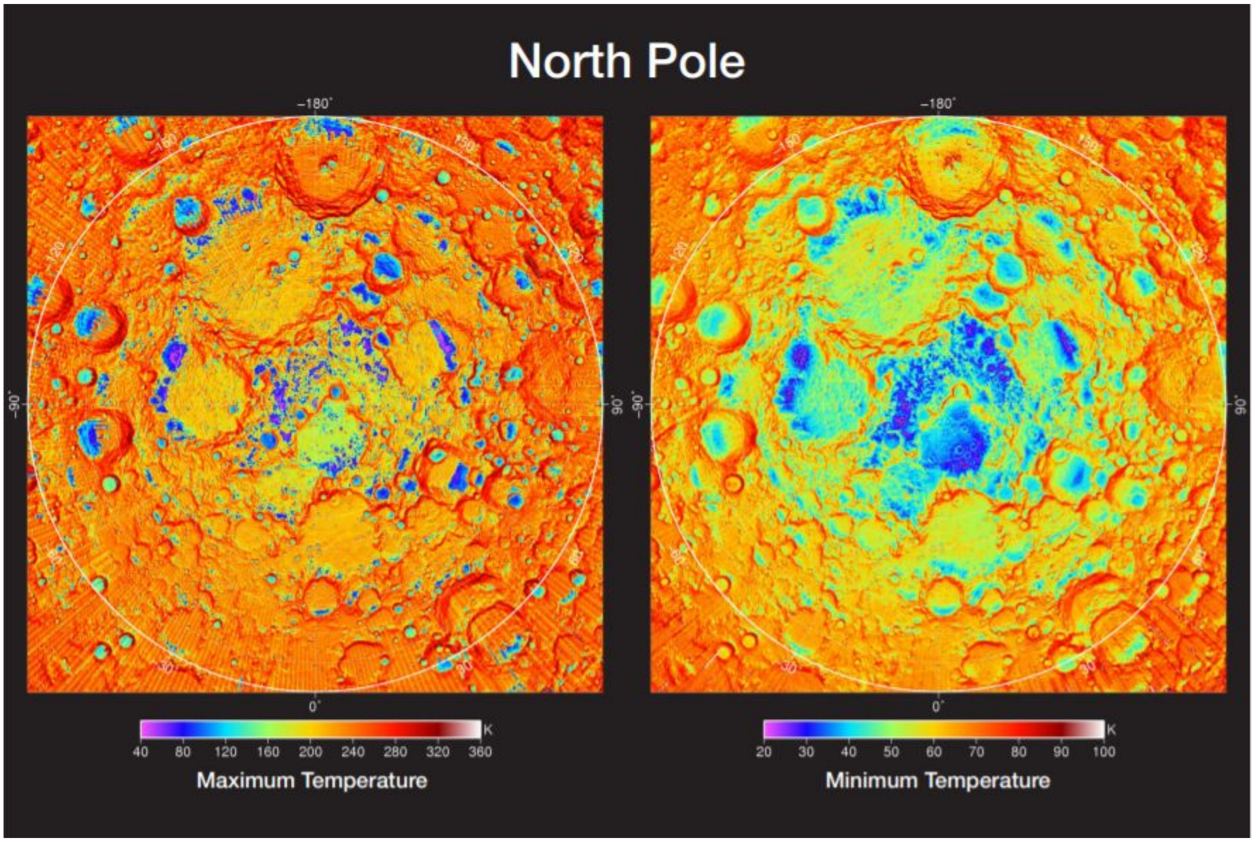


Figure 5 : "LUNAR RECONNAISSANCE ORBITER: Temperature Variation on the Moon" (NASA)

Should the lunar outpost be built at the Peary crater, energy would be easy to gather from the sun as the lunar North pole is in sunlight approximately 89% of the year, which is the greatest concentration of sunlight on the Moon. It is also estimated the 1.3 trillion pounds of water ice can be found in the craters found at the lunar North pole. Building an outpost at the Peary crater on the Moon would be one of the best possible locations as the crater itself has a relatively consistent temperature, there is easy access to solar energy which would be collected to power the outpost, and there is water ice in the area which can be collected and used for drinking water or broken up into Hydrogen and Oxygen to be used as a fuel source.

Another possible location could be the lunar far side of the Moon, specifically near a lunar maria since it is estimated that the highest concentrations of helium-3 are found there, as well as ilmenite, which is used for its titanium to make alloys. If desired, the location due to its lack of atmosphere could be used to set up telescopes on the Moon. However, there are more problems with settling outside of the poles: inconsistent and lower temperatures, as well as the far side of the Moon is more subject to solar winds since the earth would not be there to block it. Scouting out different lunar maria, since they are formed by ancient volcanic eruptions, could lead to the possibilities of finding more lava tubes, and finding one that is uncollapsed, since solar winds would be less of a problem for an underground base. The other main issue with the far side of the Moon is a lack of communication between earth and that side of the Moon, so colonizing it will require a communication satellite, which could cost anywhere from $50 million to $400 million, and possibly more, just to create and send the satellite to space.

A third possible location for the lunar outpost is the lunar south pole, with the outpost built in and around the Malapert Crater which is an approximately 69km crater near the lunar south pole. One of the most desirable qualities of the Malapert Crater is that the average temperature of the lunar south pole being approximately -13°C; which is very mild and many places on Earth reach that temperature. The below temperature map (figure 6) shows the temperature variation at the lunar south pole as found by NASA's Lunar Reconnaissance Orbiter.

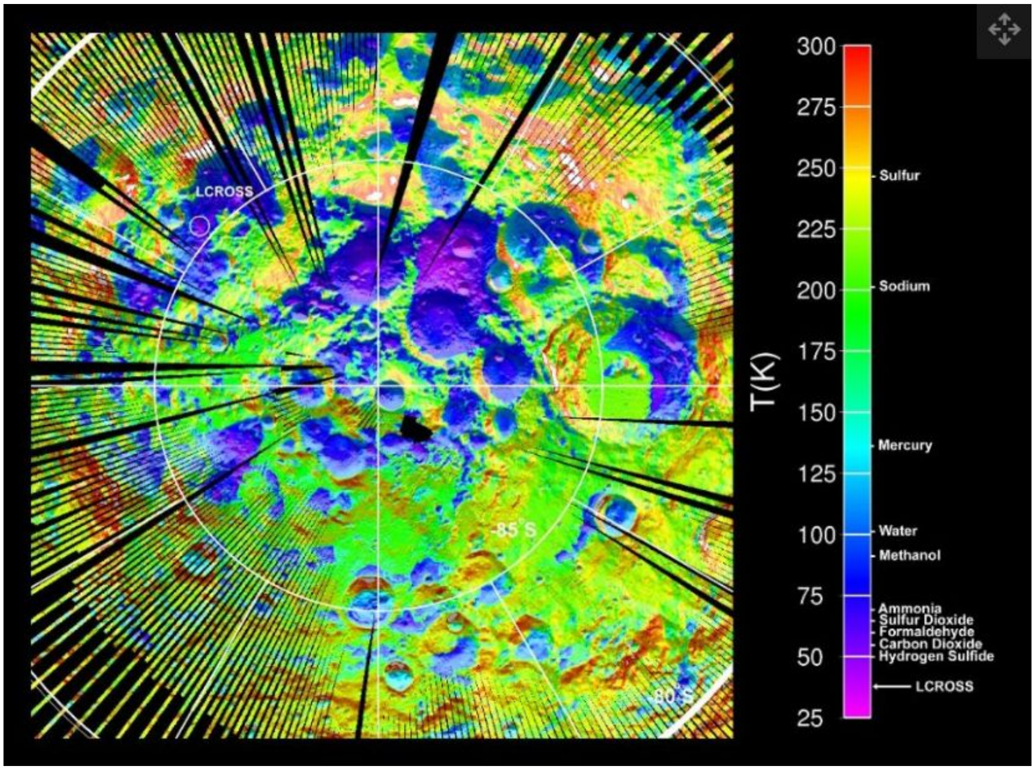


Figure 6: “LRO Diviner Lunar Radiometer Experiment surface temperature map of the south polar region of the Moon.” (Sharp, 2017)

Another desirable quality of the Malapert Crater is the Malapert Mountain which is an approximately 5km mountain at the rim of the crater, this mountain is in sunlight approximately 90% of the year (this is 4% higher than the average sunlight the lunar south pole receives). The major detriment of the Malapert Crater is that no large concentrations of water have been found near the lunar south pole which would force the outpost to either rely on water from Earth or send autonomous robots to other locations on the Moon with higher concentrations of water (such as the northern pole). An added benefit of the Malapert Mountain is that the area to the rear of the mountain is in the radio shadow from the Earth, this would allow for a radio telescope to be built in this area without interference from the Earth.

Building an outpost on the far side of the Moon at a lunar maria only has the benefit of high concentrations of Helium-3 and Ilmenite because of this being the only benefit to the far side of the Moon it would not be an ideal location for an outpost. When all the factors are considered the Peary Crater and the Malapert Crater are two of the best options for lunar outpost locations. The main differences between these two locations is temperature and water; the Malapert Crater has a much more mild temperature than the Peary Crater, while the Peary Crater has easy access to water whereas the Malapert Crater has only small amounts of water in the area. Between the Peary Crater and the Malapert Crater the Peary is the more desirable location for an outpost as easy access to water at a consistently colder temperature is far better than low access to water at a mild temperature.

Problems of Lunar Base

Low Gravity

The human body is not built for long term weightlessness in space, as our body has numerous muscles used for maintaining posture, as well as our bones must be strong enough to support ourselves as well. Since space is a more weightless environment and the Moon's gravity is much weaker than the earth's, prominent leg muscles used for helping a person stand up begin to weaken and get smaller, since they are not being used as much. According to NASA, if a person were to do no exercises in a weightless environment, that person within a 5 to 11 day period of time could lose up to 20% of their muscle mass. The human body also begins to readjust which muscles are needed, and faster response contracting muscles begin to replace the slower endurance muscles that our body uses for maintaining posture. Bones are also affected since there is now very little stress on the bones, causing the bone metabolism to change and in a lower gravity environment, bone tissue can begin to deteriorate. The amount of bone tissue lost in the body per month is about 1.5%, especially for bones like the lower vertebrae, hip, and femur, bones that are core to supporting the body's weight while moving and standing. Symptoms of this rapid decay in bone strength can lead to frail bones and Osteoporosis, as well as Osteoporosis like symptoms in bones aside from the spine. The effects appear to be reversible for an astronaut coming back to Earth but the long term effects are yet to be understood. An astronaut that is in space for 3-4 month can usually take about 2-3 years to regain the lost bone density. There are also other potential issues that could arise with the human body by being in space, like the loss of bone density increasing the calcium levels in blood which can lead to kidney stones as well as damaging and hardening soft tissues.

Radiation

One of the dangers for astronauts to keep in mind for colonizing the Moon is space radiation. The earth has the Van-Allen belt to absorb the ionizing radiation whereas the Moon does not have one. Some of the radiation is caused from solar flares from the sun, while others are from galactic cosmic rays which come from beyond our solar system. The danger is the effect of radiation on the human body where overexposure to radiation damages the cells in the body due to the DNA in them breaking down. According to NASA, astronauts are usually exposed to about 50-2,000 mSv, Milli-Sieverts, of radiation during a 6-month mission, which for perspective, 1 mSv of ionizing radiation is about equal to three chest x-rays. There is such a wide range since Galactic Cosmic rays vary in strength and occurrences and radiation that is even trapped in Earth's magnetic field will affect astronauts. This is a significant amount of radiation that could lead to a plethora of long-term and short-term health problems. For long-term effects, central nervous system damage, death, and cancer. The short-term effects include diarrhea, nausea, vomiting and changes to the blood. The only current mitigation for this radiation is career limits for space flight, barring people after being in space for a certain amount of time to limit the astronaut from experiencing enough radiation to cause long term problems.

Going Underground

So far, a lot of focus has been put on searching for lava tubes that are intact and habitable as it wouldn't require special equipment to inhabit them. That search has been unsuccessful so far and many of those tubes are collapsed, so creating your own space would need to be the next step since it is widely accepted and understood that a colonization on the surface is far too dangerous due to radiation waves and debris traveling at high speeds, which can easily damage anything in its path. Some sort of tunneling boring machine, like what we have on earth, could work out great, if we could get them there. The price of transporting even kilograms of supplies is high and the current machines on earth weigh a few metric tons. The designs of the machines would need to be optimized to be as lightweight and sturdy as possible, since they would have to be sent to the Moon. Assuming the machine can be sent to space, ignoring the cost, it will need to be fully automated and require repairs from time to time as it rips apart dirt and rock. A human or a separate robot made for repairing would be required when the drill needs to be maintained.

Another major issue that would need to be solved but could be helped by some of the reasons a Moon colony is even being considered is powering the robot. According to phys.org, a 4-meter tunneling boring machine would need about 2,000 kilowatts of energy per day.

Solutions for Lunar Base

Low Gravity

The current methods of alleviating some of these side effects of space are specialized workouts that astronauts perform. One is a bicycle workout that is used to measure heart rate and is good cardio. Another is a weighted treadmill, where a harness is strapped to the astronaut preventing them from floating off the treadmill. Walking and running is important for maintaining the health of an astronaut's bones and muscles as it helps alleviate the issues of those muscles and bones not experiencing the stress of gravity on Earth. The last workout that is commonly used is called RED, or Resistance Exercise Device, which is a weight lifting like machine used for total body workouts, from squats to arms and leg, as well as heel exercises, to try to workout as many of the different muscles as possible to prevent them from decaying.

Figure 7 : "Astronaut performing kneeling lift with ARED device" (NASA)

Some students at the University of Colorado Boulder are working on a way to have artificial gravity for astronauts to be able to use in space. A method that this could be achieved is that a wheel of sorts has the astronauts attached to it and are spun at a certain speed. The wheel is spun at a certain speed and that velocity forces the person down onto a metal platform at the base of the wheel, and this velocity mimics gravity here on Earth. This would be used like a sauna, the analogy the students related it to, that each day in space the astronauts would go into the machine and get their daily dose of gravity. There are numerous issues with this idea even though this is the most realistic method of implementing artificial gravity today. The longterm effects of how this will affect astronauts is unknown, the students do not know how effective and how often this needs to be used by an astronaut to prevent the muscle and bone reductions in space. The other issue is the glaring issue of being spun on a wheel: motion sickness. Slow progression and usage of the wheel does seem to yield results that astronauts can work their way up to higher speeds without getting motion sick, so this could be a part of astronaut training. The other issue is the size of the wheel and sending it into space. The larger the wheel, the less motion sickness a person could experience because the wheel does not need to be spun as fast to achieve this artificial gravity, but with a smaller wheel, it is easier to send to space but requires more training to overcome the motion sickness as it needs to be spun faster to achieve the affect.

Radiation

Space radiation poses a large issue with colonization, as building underground bases surely helps, but you still cannot be on the surface or beyond. There are space weather services that monitor radiation and flares, but how can an individual living in space better protect themselves from radiation? A current creature that is being studied called a Tardigrade could hold the key. According to National Geographic, tardigrades have a reputation for their high survivability skills in a drastically changing environment, and while they can survive extreme climate changes, the vacuum of space, and more importantly, they are able to protect themselves from larger amounts of radiation than a typical person could endure. They survive by being able to directly protect their DNA with a protein that is termed Dsup, or damage suppressor.

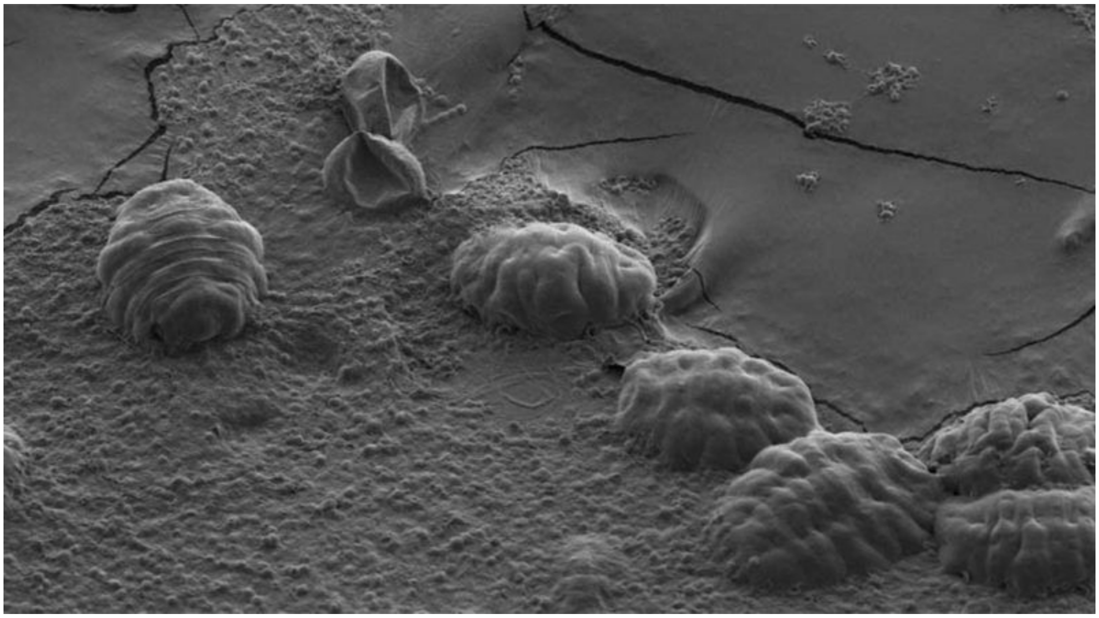


Figure 8: Tardigrade protecting itself with Dsup (Sciencenew.org. T.C. Boothby)

The protein binds itself to nucleosomes, which are used in DNA to compact the DNA structure into a coil. The Dsup binds itself to strengthen the nucleosomes, making the DNA require much more ionizing radiation to unwind the DNA. By protecting nucleosomes, it protects the DNA from the negative effects of radiation. The key for space colonization would be taking this kind of protein and modifying people who will colonize space to produce their own so that the DNA in their body is more resilient to external interference. There are some moral implications to modifying a person but the payoff for a successful and thriving space colony and beyond the Moon would be extraordinary, as well as the other uses for this kind of protein in treating cancer more effectively.

Going Underground

A solution for how to power the machines on the Moon would be either a fusion reactor that uses the Helium-3 that is abundant on the Moon, but that would require some prior base already being set up. Solar energy would be plentiful but having solar panels on the tunneling machine would be pointless since its whole purpose is to go underground, but batteries could be charged with solar energy and when the machine gets low on charge, returns to have its battery changed. One machine alone would take months as the world's largest tunneling boring machine, Bertha, used 18,600 kilowatts of power and only moved at 35 feet per day, according to the Washington State Department of Transportation.

Figure 9 : Picture of Bertha the tunneling boring machine (wsdot.wa.gov)

Being restricted in size by what can be sent to space puts a large hindrance and a lot of resources just to have an automated machine digging out a suitable area for colonization, but if a lava tube that isn't collapsed cannot be found, then it may be the only option for getting under the surface. Explosives could be another solution for tunneling but bringing explosives from earth can't be a possibility considering how much would be needed to send a rocket full of explosives just for excavation. According to the National Park Service (NPS), for their rock removal they require a 1-pound pouch per cubic yard. Depending on the size of the colony, it could require hundreds of pounds of explosives. Large scale bombs have been used on the Moon but using hydrogen bombs or other large scale explosives would not be ideal for making a relatively small, compared to a hydrogen bomb's 5-10 mile explosion radius, tunnel and underground base.

Energy for Earth

Although projects such as the He-3 project seem prosperous for the future, it is important to understand that it might take us quite a very long time for us to be able to extract He-3 from the Moon and get it to earth. Moreover, even if we were able to extract He-3 or any other mineral from the Moon, we would need energy to carry out such a process and preferably clean energy. Therefore, we also looked into other possible renewable energy resources such as space and earth mirrors for solar energy, ocean currents/ tidal energy, and the opportunity of replacing Uranium by Thorium in the current nuclear fission power plants since Thorium fission is much safer and Thorium element is available in much more abundance compared to Uranium.

He-3, Space and Earth Mirror Potentials Comparison

According to the reports, solar energy is still only contributing about less than 600 TWh of more than 157000 TWh global power demand. This is a very small supply from the sun energy and the reason for this is that there always has been concerns with the availability of the sunlight on earth surface. As of current, most available solar energy plants are of earth mirrors which are not fully efficient or reliable because the sunlight is only available for a few hours per day in each part of the world. However, in some parts of the world like Africa, Middle East, most of South America etc, there is enough sunlight in the day and throughout the whole year, and with use of the surface/earth mirrors, large batteries can be used to stock enough energy that can serve the nights. An example of this is Qatar which is currently developing a project known as Al Kharsaah power project which will develop an 800MW Photovoltaic power plant. This size of plant can fully supply power to a country like Rwanda which only has 218MW power generation of recent which satisfies about 33% of the country's population. Nevertheless, with only less than 1% global energy supply being from solar energy, we can argue that this has not been much of a success though the success is possible given cases like Al Kharsaah power project. We also have to keep in mind that some countries have long cold winters which means less sunlight which makes earth mirrors installation less practical in such areas.

For the above reasons, the future of solar energy lies in space where sunlight can be available all time and at any place using the space mirrors. With the use of large, ultra-lightweight reflectors in orbit around earth which can reflect the sunlight onto large-scale solar power firms that are placed down on earth and can keep the solar power plants on earth operate normally and full-time even in the dark. These space mirrors would not only supply sunlight to photovoltaic and thermal collectors for electricity and heat, but they would also illuminate cities and other places in need of light, illumination of agricultural places to increase the growing season and can also be used in attempts for weather modifications. Another alternative with space mirrors is to introduce power stations into space which would transform sunlight into microwaves while in the orbit. These microwaves would be received by the antennas located on earth which will then transform those microwaves back into electricity.

Largely known, Japan Aerospace Exploration Agency (JAXA) is running a project on space mirrors which would have Japan generate 1GW of electricity by 2031.

However, solar energy might be not enough to satisfy all the energy demand. Yes, the basic energy use such as lighting, cooking and basic home care energy can be satisfied but with the large industrial energy demand, the solar energy can be insufficient regardless. Therefore, other more powerful renewable energy sources remain in radars of scientific researchers. One of these is Helium-3 (He-3) which can be used in fusion reactors. A fusion reaction of He-3 and deuterium produces a lot of energy (about 18.4MeV per one molecule of He-3 and deuterium fused together). Moreover, the use of He-3 fusion reactors can help the world get rid of current fission reactors which release a lot of radio-active wastes that are dangerous to human beings and the environment in general. Thereafter, it is a revolutionary act to the world to have access to He-3, but it is never going to be easy as He-3 is currently rarely accessible on earth as it can only be found as a byproduct of the destructive deuterium-deuterium reaction. On the other hand, He-3 is abundantly available in some other planets and satellites in space. Thus, researches are ongoing on how He-3 can be extracted from such places like the Moon and brought to earth for more and clean energy production.

Ocean Currents/Tidal Energy

Slightly more than 70% of earth's surface is made of water and about 97% of earth's water are oceans. Therefore, it is only understandable that the world should look forward to getting energy from such a massive source and lately there have been more international efforts towards the development of ocean energy which presents a potential of 450GW and $550 Billion globally (Finkl & Charlier, 2009).

But what makes ocean energy special? With a lot of movements of ocean water mainly caused by the gravitational attraction between the earth and orbiting satellites such as Moon and neighboring planets, winds, speed of the waters and high densities of water as a fluid result in a significant amount of kinetic energies which can be transformed into needed electric energy. That being said, the amount of electric energy produced by ocean currents depends on the above kinetic energy factors and the specifics of the device used to transform that kinetic energy which are the efficiency of the device, the swept area, the area of the computational cell, and the number of devices per unit surface area. This device is a turbine which operates as wind energy turbines and the Kinetic power of it can be calculated using the formula:

$$P_k=\sum(½)p|V|^3E_fA_sA_cN \qquad (2)$$

where ρ is the water density, V is the water speed at the turbine's depth, E_f is the efficiency of the turbines, As is the swept area of the turbine, Ac is the surface area of the computational cell and N, the number of turbines per surface unit area. This kinetic power of ocean currents produces much more energy than that of wind due to higher density of water compared to air. According to the National Oceanic and Atmospheric Administration, the average Gulf Stream speed is 4 miles per (6.4Km/) which is roughly 1.78m/second. With this information and knowing the density of water which is 1000kg/m^3, we can calculate the amount of kinetic energy that can be produced in any area. Assuming a speed range of 1.6m/second to 2m/second, we will calculate the minimum and maximum kinetic energies at any place. Using $K=1/2mV^2$, the energy flowing through any place would be between 1280joules/m^3 and 2000joules/m^3.

$$Vo= 0.7\times0.97\times4\times R^2\times d \quad (3)$$

In this, Vo is the Volume of Ocean Water, 0.7 is the 70% of earth's surface that's water, 0.97 is the 97% of earth's water surface that is oceans, R is the radius of earth and d is the depth.

$$Vo= 0.7*0.97*4* (6.37 \times 10^6 \text{ m})^2* 4.27*10^3 \text{ m} \quad (4)$$

$$Vo= 1.4744 \times 10^{18} \text{ m}^3 \quad (5)$$

Therefore, the total maximum energy available for extraction from ocean currents would be equal to:

$$E_{Total}=2000\text{joules/m}^3 * 1.4744 * 10^{18} \text{ m}^3 \quad (6)$$

which is 2.9488×10^{21} Joules. This calculation gives an estimate of how much energy can be extracted from one place, but the energy ration can be a little smaller than that depending on the specifications of the turbines. However, this energy can also be way higher in other areas where the speed of the tides is higher than 2m/second. In a place like the Bay of Fundy, the average speed of the tidal currents in the Bay of Fundy is 5.1m/second which implies that up to 13000Joules/m^3 can be extracted from there. The map below shows the average surface kinetic energy on the U.S coast:

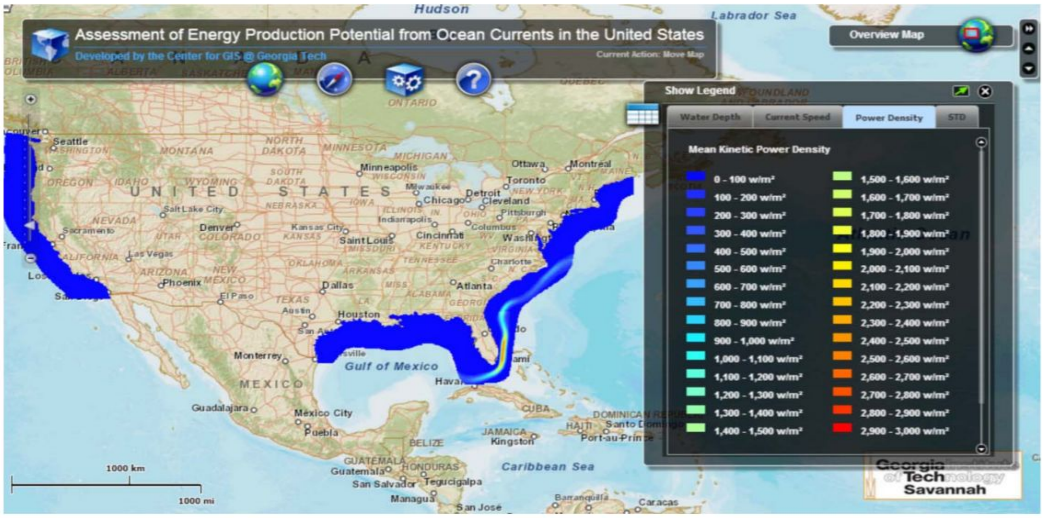


Figure 10: A GIS map that represents the mean surface Kinetic Energy on the US Coast (Energy.gov)

Thorium Fission Reactor

Nuclear power is another source of energy that is largely used. Nuclear energy can partially be considered as a clean energy because they do not consume biofuels that contribute to global warming yet generate large amounts of energy. 1kg of Uranium produces up to 24,000,000Kwh of energy which is way more than what coal, wind, hydropower… can produce (ovo energy, 2018). This makes nuclear power very important to the world's energy industry. However, the possibility of nuclear accidents and storage of radioactive materials/wastes produced during nuclear power generation remain risks that we would want to keep as minimal as we can. In attempts to reduce those risks, different technologies and various resources are explored.

For a long period of time, Uranium has been the major source of nuclear power. However, we can get concerned that at some point in the coming decades, the world can run out of the Uranium that we can exploit. The scarcity of Uranium in the future is not the only concern, but the results of the uranium fission reaction brings the world into an attention of finding a much safer nuclear element that can possibly replace the uranium.

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow [{}^{236}_{92}U] \xrightarrow{85\%} fission\ (e.g.\ {}^{139}_{56}Ba + {}^{94}_{36}Kr + 3\ {}^{1}_{0}n) $$

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow [{}^{236}_{92}U] \xrightarrow{15\%} {}^{236}_{92}U + \gamma $$

With the use of thermal nuclei in this reaction, highly radioactive fragments are produced, and these undergo further decays to stabilize themselves. Nevertheless, energy is produced with these fragments in the form of heat and gamma rays.

For more stability, scientists have been looking into the possibility of Thorium replacing Uranium in the fission industry. Thorium is much more abundant in nature than Uranium, yet more fertile instead of fissile. This means, Thorium produces less unstable radioactive wastes which makes it better to the environment. Moreover, for the same amount of both elements, Thorium produces 35 times more energy than Uranium (Ting, 2015). Therefore, 1Kg of Thorium would produce about 840,000,000Kwh compared to just 24,000,000Kwh generated by 1kg of Uranium. With this amount of energy generation potential, its abundance in nature, and less radioactive waste effects, Thorium holds the potential to revolutionize the fission industry.

Despite all possible advantages of Thorium as a nuclear reactor fuel, there are lots of drawbacks especially associated with the technology that is not adapted to Thorium's complexity yet. First, full extraction of Thorium seems a little more complicated because it is present in various rare earth ore minerals as presented in the table below:

Ore	Composition
Thorite	$(Th,U)SiO_4$
Thorianite	$(ThO_2 + UO_2)$
Thorogummite	$Th(SiO4)_{1-x}\,(OH)_{4x}$
Monazite	$(Ce,La,Y,Th)PO_4$
Brocktite	$(Ca,Th,Ce)(PO_4)H_2O$
Xenotime	$(Y,Th)PO_4$
Euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
Iron ore	Fe + rare earths + Th apatite

Figure 11: Thorium Ores Composition (Magdi Ragheb)

With its occurrence in that many different ores with other different elements including radioactive ones, the extraction would be much more complicated. This can also justify why in the developments or exploration of Thorium reactors; different approaches are considered. Those are: the liquid molten Thorium Fluoride salt, pebble bed graphite moderated and Helium gas cooled, seed and blanket solid fuel with a Light Water Reactor (LWR) cycle, and a driven system using fusion or accelerator generated neutrons. (Ragheb, 2011). As of 2020, more than 54 nuclear reactors are under construction around the globe and this keeps increasing over time. More efforts and investments are necessary regarding the exploitation of Thorium.

Look into Future

Certainly, as the world's population grows and technology advances, the energy demand will keep going higher. If we keep using the same resources we are using, there is a high chance that in the near future these resources will be gone. Therefore, the world needs an increased exploration and exploitation of more renewable energy resources. However, exploration of some resources itself might take ages, especially the resources in space. We can not assure that full exploitation of resources from other planets or satellites will be possible in the nearest future and this remains the same with the establishment of a lunar base. However, it is very important for humans to know that the potentials are there and having such a base would benefit humanity a lot. As a result, this awareness will cause more and more research on the matter for all individual, institutional, governmental, and hopefully international levels as there are still more unanswered questions about this utilization of space despite the undoubtable benefits. We can expect to see increased investments from different governments and private companies in efforts to make this become true.

As this space exploitation might take too long to happen, there are other renewable energy alternatives that we will see growing in the meantime. Solar energy is already one source of energy that has been in place for a while and as the energy demand grows, resources decrease, and as one of the efforts to reduce the greenhouse effects, we might see a significant growth in the use of solar energy in many industries. This solar energy has a lot of advantages as its technology is already known, available, and it is one in which investments have already been started and lasted in some countries. For example, countries like Morocco, Tunisia, Qatar, etc have big solar energy projects in progress to the level they can export electricity solar energy across countries and continents. Additionally, in developing countries where only a small percentage of the population have access to electricity yet the sun is available for most of the year, the governments partner with private companies to supply solar panels to people that can afford them and those panels fulfill their basic need of electricity such as lighting, and supplying energy need for the basic home materials such as TV, PC, fridge… We suspect to see the use of solar energy growing largely into other industries such as automotive. Moreover, we will also see a growth in the use of other renewable energy resources that are not optimally exploited currently such as the ocean energies and a look into exploitation of other safer and more efficient mineral materials such as Thorium. If these alternatives are not considered, there is going to be a big increase in the cost of energy, insufficiency of energy and not to forget severely bad impacts on the climate.

Conclusion

This report was able to highlight the different types of technological advancements that are needed to be further developed in order for a Moon colony to succeed. However, with the right technological advancements, the Moon proves to be a sturdy stepping stone for spreading life beyond the Moon. Having a Moon base is also beneficial to the residents on Earth as there are plenty of resources that can help sustain the energy of our planet in a cleaner and more efficient manner as our population continues to grow. The Moon was highlighted to have numerous commercial interests for its metals and helium-3 to mine for, as well as it being a testing ground to monitor the effects of prolonged low gravity. The Moon could also be the initial spaceport for future space travel.

The paper also went in depth about the needs for sustaining a Moon base. Food and water technology needs more advancements but is well underway for being able to sustain life on the Moon and this technology can be adapted to other planets' and their habitats. In this paper we also highlighted how advantageous solar energy and helium-3 would be for fueling both the Earth and the Moon base, since there can be much more direct sunlight and room for the building of solar panels. Maintenance would still be required but the construction of repair robots would help in keeping panels intact. To start off the colony, a well trained and educated crew is required.

The paper also analyzed a few more issues and provided solutions for overcoming them. Low gravity takes a toll on the human body and the advancements made in equipment and workout strategies to maintain the strength of astronauts is required to maintain their health. Radiation poses a large threat to people but having an underground base and advancements in learning about tardigrades can help the human body become more protected and resistant to dangerous radiation that would negatively affect the colonists long term health.

We also explored more in depth how Helium-3 and space solar panels would benefit Earth with providing more energy. Large scale space solar panels could fuel a larger portion of the world's energy, as solar only contributes 1%. Microwaves and Helium-3 would also be able to overcome the need for fossil fuels and be able to have a significantly cleaner energy for the world. In addition to these forms of energy, tidal energy would help continue to generate power in conjunction with these other methods and would also be a clean form of energy to power the world. The exploration and colonization of space would give Earth the resources it needed to more properly fuel itself and in a way that's better for the environment.

IQP Suggestions

After our experience with this project we feel that there are a few ways in which future teams can expand off of our work and begin the process of more off world bases. To expand on our specific research future groups could develop a timeline for a lunar base to be built and established. Future groups can also look into the psychological effects that would occur to people who spend large periods of time on off world bases with a limited number of crew members. Another important topic that should be looked into is the cost that would go into the creation of a lunar base.

Once a lunar base is created, the next logical step is to create a base on other planets within the solar system; this includes the creation of a base on the surface of Mars or on the surface of Venus. When considering building a base for a human settlement, Venus is the considerably less desirable location due to the highly hazardous environment. While researching both of these planets it's possible to explore the topic of terraforming the planetary surfaces to make them more easy to live on. Future groups can look into the creation and purposes of bases to be built on Mars or Venus.

Bibliography

"Alaskan Way Viaduct - Tunneling." *WSDOT*, www.wsdot.wa.gov/Projects/Viaduct/About/Tunneling.

Dunbar, Brian. "Your Body in Space: Use It or Lose It." *NASA*, NASA, 9 Apr. 2009, www.nasa.gov/audience/forstudents/5-8/features/F_Your_Body_in_Space.html.

Poels et al., "Entire liquid mirror telescope system." 2001, digital image, accessed 11 July, 2020, <https://www.adass.org/adass/proceedings/adass00/P3-13/>

NASA. "Astronaut Selection and Training." *NASA*, 28 Nov. 2011, www.nasa.gov/centers/johnson/pdf/606877main_FS-2011-11-057-JSC-astro_trng.pdf.

NASA, "LUNAR RECONNAISSANCE ORBITER: Temperature Variation on the Moon", digital image, accessed 18 July, 2020, <https://lunar.gsfc.nasa.gov/images/lithos/LROlitho7temperaturevariation27May2014.pdf>

Saey, Tina Hesman. "How Tardigrades Protect Their DNA to Defy Death." *Science News*, 10 Oct. 2019, www.sciencenews.org/article/tardigrades-dna-damage-radiation-death.

Sarkissian John, "Schematic diagram of the Parkes Telescope." digital image, accessed 11 July, 2020, <https://www.parkes.atnf.csiro.au/news_events/apollo11/parkes_telescope.html>

Sharp Tim, "LRO Diviner Lunar Radiometer Experiment surface temperature map of the south polar region of the Moon.", digital image, accessed 18 July, 2020, <https://www.space.com/18175-moon-temperature.html>

Strain, Daniel. "Artificial Gravity-without the Motion Sickness." *CU Boulder Today*, 6 Feb. 2020, www.colorado.edu/today/2019/07/02/artificial-gravity-breaks-free-science-fiction.

Stolte, Daniel. "Documentary Shows How a Veggie Garden for the Moon Can Sustain Life on Earth." *Phys.org*, Phys.org, 7 May 2014, phys.org/news/2014-05-documentary-veggie-garden-moon-sustain.html.