Luna For Living

Abingdon School

By Team Farr Out

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Meet The Team

Ed Spackman

I am currently studying Maths, Physics and Chemistry in the Lower Sixth and took on this project as I have always been interested in space exploration and it seemed like a good way to further my interest in engineering. I was the joint team leader for our L4L project and was mainly involved in the energy and logistics side of the project as this is what interested me the most. In addition, I helped to research the advertising business and have overseen and linked all the other areas.

Will Farr

I am Will Farr and the team was named after me. I am the joint leader of Team Farr Out L4L and I have mainly been involved in the justification of ideas as well as one of the creative minds behind the railgun. I am studying Maths, Physics, Chemistry and Economics. Space is an area of unique interest for me. Ever since I was 5 years old, I was fascinated by the idea of Moon landings and space exploration, and always wanted to do that myself. This has been a deep dive into one of my closest interests and has provided so much insight into the professional side of space research and a taste for the sheer effort that goes into such research.

Ollie Paton

I study Maths, Physics, Economics and Geography at A-level and I am taking part in the Blott Matthews challenge as I have always had an interest in engineering and I wish to widen my knowledge of what the future of space could be. As a part of team Farr Out I have largely been involved in researching and developing our ideas about sustainable living on the Moon. I have also played a part in researching the use of advertising as a part of phase one and I found this interesting due to its link to economics.

Alexander Billington

As someone who is very interested in Physics, I decided that the Blott Matthews challenge would be an interesting activity to do. I am studying Chemistry, Further Maths and Physics due to my interest in continuing Physics at a higher level, which sparked my interest in this engineering challenge. I worked on the entirety of both of the health sections, as well as the nutrition and the mining sections, and finally the housing layout and designs of the rooms. I also came up with our group's railgun idea.

Jamie Calver

I currently study Further Maths, Physics and German. I decided to take part in Blott Matthews to fulfill my interest in physics; I also enjoy the creative aspect the challenge brings. I have mainly worked on the plan for food, the rover, and how oxygen will be supplied for the inhabitants.

Jasper Trilk

I heard about the Blott Matthews Challenge that students from Abingdon School participated in last year and thought that it would be a very interesting competition to take part in. Additionally, the Challenge complements my STEM A-levels and wider interests. I was ecstatic when I found out what the challenge was going to be this year as space and, specifically, space flight are of particular interest to me as an aspiring astronaut. My role in the team was to construct and solve the equations and the science in relation to the railgun. The caveat of the location presented a unique set of challenges to overcome.

Tom Owen

I am studying Maths, Further Maths, Physics, Chemistry and Art at A-level. I decided to take part in the Blott-Mathews challenge, because I've always had an interest in futuristic designs and engineering. I have done most of the technical drawings and looked into various designs to recycle water, how to filter it and extract it from the lunar ice. I also helped design the features of the mining robots.

Project Summary

In our proposal we have planned and developed what we believe to be viable economic activity on the Moon. It includes an analysis of our proposed mining business taking in the automated drill robots and train system as well as an estimate for the potential profits of this mission.

Secondly we present our permanent Lunar Base capable of housing 20+ astronauts complete with life support systems, a self-sufficient food and water supply and an overview of the proposed solar energy system.

Furthermore we have looked into the logistics of how we will transport all of our astronauts and technology to and from the Moon to come up with a two-stage solution involving a space station. Finally, we have designed a railgun capable of sending packages of mined lunar regolith back to earth to be purified and sold, as continued rocket launches would impact significantly on economic viability.

Our Business Proposal

Mining

What we will mine:

Hydrogen - 3, commercially known as tritium, will initially be our main focus: it has the potential to generate massive burst revenue due to its growing usage and extreme rarity on earth, and, due to millions of years of deposition by solar winds, it is relatively abundant on the Moon. Currently the world has 18.5kg of tritium available at a price of $30,000 per gram. However, due to increased demand because of developments in fusion technology, the demand is expected to increase by 500%, as will the price. We hope that by selling slightly cheaper tritium, we will be able to initiate a plethora of scientific innovation resulting in tritium fusion, clean, renewable energy for all and a greatly increased global demand for tritium allowing us to profit.

The moon also contains many metals that are considered rare and extremely useful on earth such as titanium and magnesium (amongst others). Parts of the Moon have up to 10 times as much titanium as rocks here on Earth do, and titanium is a metal with growing value in today’s world due to its strength and ability to resist high temperatures and electrical currents. In addition to this, it is non-toxic and is often used in medical implants with other metals as an alloy. Titanium prices are generally all around $60 per kilogram, while magnesium’s price has peaked to $6,000 per metric ton and calcium’s price is approximately $110,000 per metric ton. Both magnesium and calcium are found in relatively high concentrations on the Moon however their prices aren’t enough for us to ship them back to earth as it would be unprofitable as is explained in the economics section. It is also unprofitable to ship back titanium ore as its value requires bulk transportation that our railgun cannot provide.

A SpaceX Star ship has a mission cost of $2 million and can carry 100,000kg
Ilmenite (titanium ore) is 32% titanium
So each Starship contains 32,000kg of titanium
Titanium is $60 a kg so that mass of titanium is worth $1.92 million
$1.92 million is less than $2 million so using SpaceX Starships to transport ilmenite is unprofitable

22% of certain parts of the Moon are composed of silica : this is a vital compound for our Moon industries due to its use in our solar panels, and so we must extract it from the lunar regolith before sending the regolith back to Earth. This process is explained in the energy section of the document.

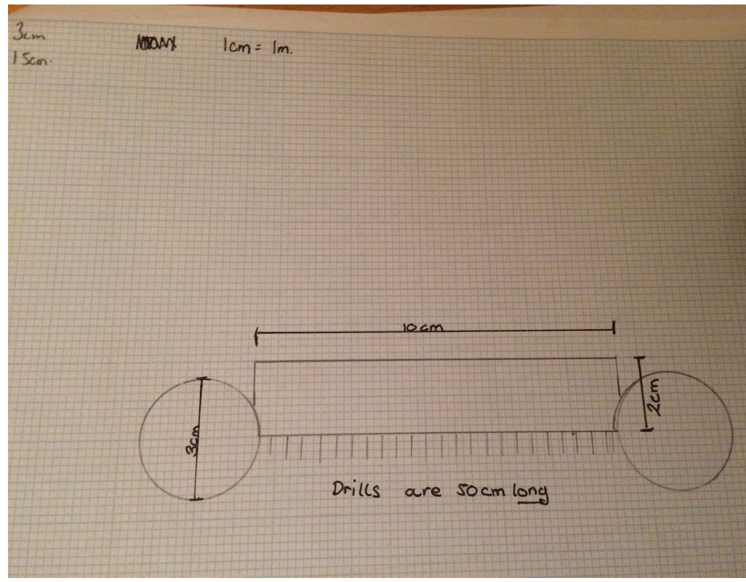
The Issues:

The main challenge of lunar mining is the movement of the equipment from Earth to the Moon: we must lift roughly 100 tonnes of equipment out of Earth's orbit. This will likely require specific supply lifts to maximise efficiency.

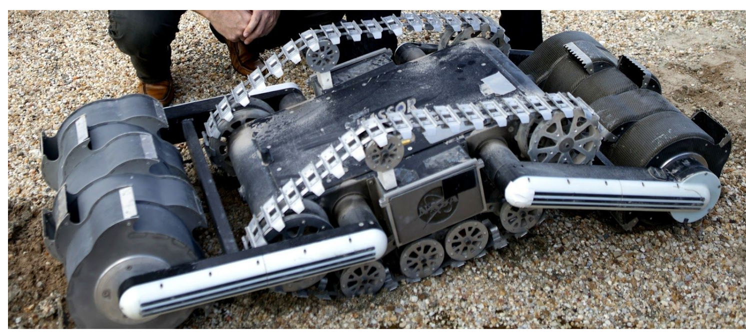
A surprising challenge that was encountered during research, however, was that traditional mining methods will simply not work, with blast mining sending out shards of lunar regolith that will not be slowed by air resistance and have very low gravitational deceleration: these combine to create fast-flying projectiles that are extremely likely to damage any nearby mining equipment and even personnel who are managing said equipment.

In addition, we considered mining tritium by using a parabolic heater to heat lunar regolith to 1273K and then collect the evolved gasses. However, due to the poor thermal conductivity of lunar regolith, this isn't possible. As a result, we also considered using regular boring. While this is not a risky method, we decided it would be far too time-consuming should only traditional single drills be in use. This led to the conclusion that, rather than using single drill bit devices, multiple drill bits should be used to fracture large amounts of terrain at once, drastically increasing the rate of mining. An issue with this is that very dry and statically charged lunar dust will build up on the surface of the drills, and possibly even enter the mining rover, damaging its machinery. To combat this issue the lunar rover will be disassembled once every month, and the individual pieces washed to scour off any lunar dust, which should ensure that it doesn't build up and damage the rover. Over time, parts of the rover may still be eroded, in which case replacement parts will be shipped up. This will, however, be minimised to keep expenses as low as possible.

How we will mine:

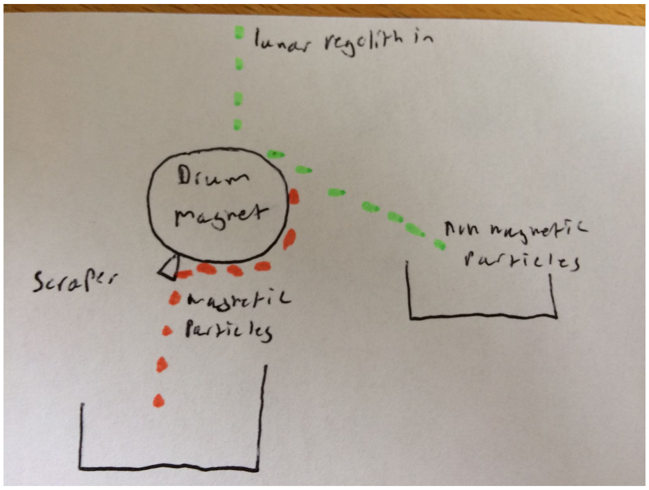


The mining rover that we will use will consist of a 10 x 10m panel of steel that houses one 0.5m long, 0.05m radius drill bit for every meter squared of its surface. This is a volume of $5m^3$ and, as the density of lunar regolith is $1500kg/m^3$, this means we will mine 7500kg of lunar regolith every length the convoy moves forwards. As we want to mine about 800 tonnes an hour, this means the convoy needs to move at just over 1000m per hour or 0.278m/s. These drills will be used to fracture the lunar surface, turning it to rubble which can easily be collected.



The drum will rotate pulling in the fractured lunar regolith and depositing it onto a conveyor belt (sadly the original image is copyrighted but we found a replica). This conveyor belt then passes the lunar regolith down the linked convoy for refinement. Firstly we will extract the ilmenite ore from the lunar regolith using magnetic beneficiation. The ilmenite ore contains titanium, iron and oxygen and so is weakly magnetic allowing for a simple extraction process. Then, after extraction, the remaining regolith is passed onto the next part of the convoy using more conveyor belts where we can extract the tritium by heating the regolith and condensing the gases evolved. The remaining lunar regolith can then be collected in storage containers and transported back to the base, along with the minerals to be used for construction purposes. Alternatively, if it isn't required, it can be returned to the trench from which it was excavated via more conveyor belts.

The process used to extract the ilmenite ore is called magnetic beneficiation and involves the lunar regolith first being crushed by a hammer-like piece of equipment to ensure that it is in a sand-like state. This lunar sand can then be poured over a rotating drum-shaped electromagnet. The magnetic materials like ilmenite will stick to the magnet and rotate with it to the other side where they can be scraped off and collected to be placed in storage bins further back in the convoy. On the other hand, the remaining non-magnetic lunar regolith will just fall onto a conveyor belt unaffected by the magnet, where it can then be transported to the next section where we can extract the tritium. Magnetic beneficiation is aided by the low gravity and vacuum environment found on the Moon. This enhances the process as the falling material falls much more slowly meaning it is more affected by the magnetic field and is sorted to a higher degree as a result. In addition, the vacuum environment eliminates any turbulence and air resistance again making the process more efficient as every grain falls at the same rate regardless of its density or size.



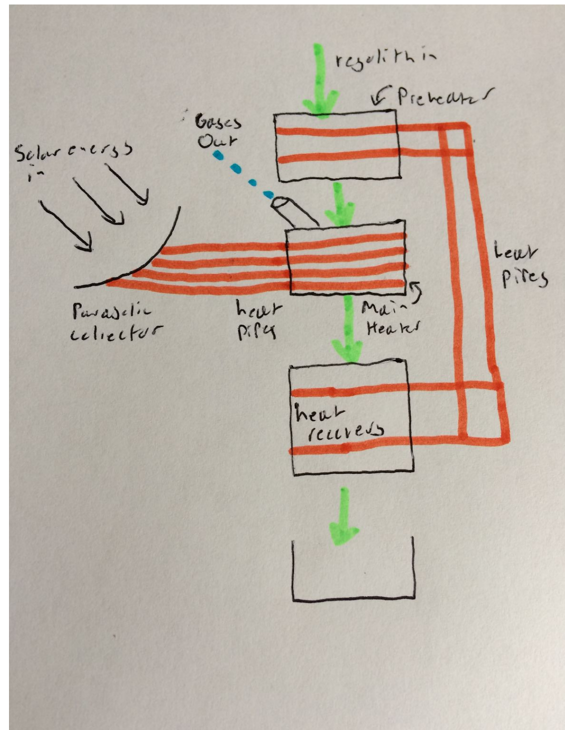
Next the remaining lunar regolith is conveyed to the next section of the convoy where we can extract the tritium. Firstly we will heat the particles to about 1023K which is the most efficient balance of extracting the maximum yield of tritium compared to the input thermal energy required. As we will be processing about 8,000 tonnes of lunar regolith an hour, we need to heat it from 25-1023K with the specific heat capacity of lunar regolith being 1000J/(K×Kg).

$\Delta Et = m \times c \times \Delta\Theta$

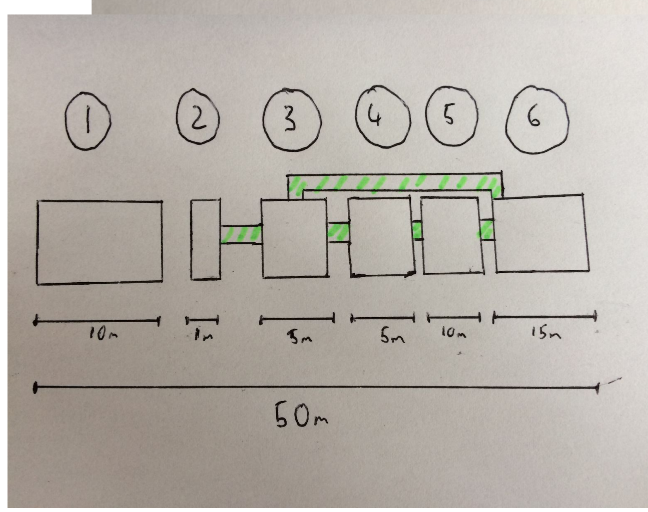
so $\Delta Et = 800000 \times 1000 \times 998$

And $\Delta Et = 798.4GJ$ every hour.

So the power required to heat this mass of lunar regolith in 1 hour is 220MW



This power can be produced by using 1 parabolic solar energy collector of radius 25m which tracks the sun, accounting for the forward movement of the mining convoy. This solar heater heats a heat-transfer medium inside of a heating pipe system (in this case, liquid lithium). These heat-transfer pipes then bring the heat to the main oven where the regolith sits in layers so as to be heated more efficiently due to its poor thermal conductivity. The tritium and other gases then evaporate due to the heat and all evolved gases are extracted and placed into pressurised gas cylinders. These gas cylinders can then be placed into the storage section of the convoy ready to be sent back to earth. The remaining regolith is then used to reheat the lithium so as not to waste any thermal energy before being dumped back into the excavation trench (if it is needed for construction, it could simply be collected).



Green areas are conveyor belts

Overall the mining convoy would be in this order:

1) Mining Unit
2) Collection Unit
3) Ilmenite Extraction Unit
4) Tritium Extraction Unit
5) Tritium Storage Unit
6) Ilmenite Storage Unit

Advertising

Advertising is a constant part of our daily lives and companies pay large amounts of money to have eye-catching adverts seen by the rest of the world. When people think of space, they generally think of exploration, freedom and development and we believe that these are all key ideas that brands would love to be able to represent in their advertising. Currently space is a hot topic, due to Trump's Space Force and SpaceX's recent developments, and so any advertising opportunities would be quickly snapped up as shown in numerous recent cases.

The Pyongyang Winter Olympics in 2018 raised over $900 million in advertising revenue in just three weeks. This shows the potential of advertising as part of our commercial activities. Elon Musk also sent a Tesla Roadster to space on his Falcon heavy rocket recently. This has been described as the greatest car advertisement ever. Pizza Hut have also entered the advertising race by paying $1 million to place their logo on a Russian rocket. In addition, they delivered freeze-dried pizza to the ISS in another publicity stunt.

Advertising has the potential to fund our mining enterprise in part and we have developed an action plan for both the company and astronauts to follow. We have decided that astronauts will have clothing and space suits branded with one of three to four main sponsors. In addition, they will constantly update social media accounts detailing their activities and could have advertisements of featured products. We will also brand our rockets (unlike NASA) and give members of the public the opportunity to send small objects to space with our regular supply trips for a price. Finally, due to our mining business, we will have a plentiful supply of 'moon rocks' which could be sold to consumers and businesses alike for a large amount of money, although the novelty of this may soon wear off. Overall this should bring in about $500 million a year.

Scientific Research

For our own and for commercial reasons, one of the modules on our Moon Base will be a laboratory. This can be rented out to generate extra income through universities and research facilities keen to run experiments in space, as shown by Stanford University's use of the new Ardulab. This is a small Arduino-based cube which contains a multitude of sensors that can be personalised by the user to run the experiment they want. Currently this cube costs $30,000 to $60,000 to send into space and universities, schools and NASA are interested in utilising it. Once in space, the device can send images and live data feeds to the user’s computer.

Team Farr Out plans to use the laboratory for its own experiments but, in addition to their own daily responsibilities, astronauts would work on behalf of third parties to manage their experiments, allowing a greater number to be run at the same time. This would allow our research lab to run experiments similar to those run on the ISS but on a much larger scale due to the higher number of personnel. One such experiment the ISS has run was about how fire behaves in microgravity and how it can be put out. It gave NASA valuable insights into how they needed to develop their space fire-fighting and also revealed a new phenomenon called ‘cool flame extinction’ (which we currently do not understand).

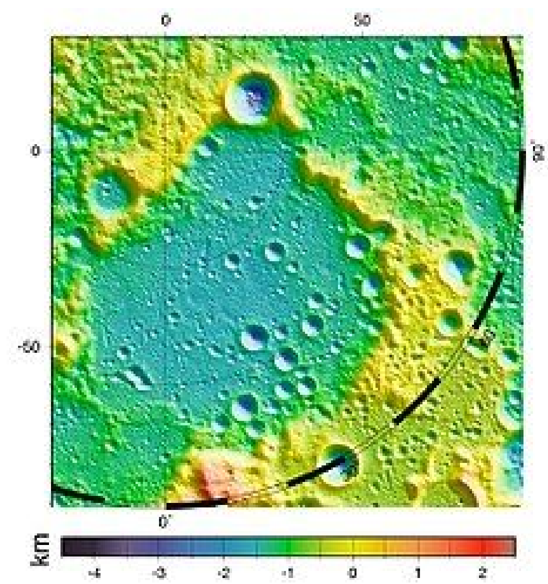
We will not rent out experimental space in our research lab immediately after landing as this would divert the astronauts’ attention from tasks such as assembling the railgun and testing the safety systems. We will, however, have it as an option later into the mission when the mining business is running smoothly.

Later in the mission, research labs could pay to send up their own astronauts on our rockets to carry out experiments. We estimate that we could charge up to $500,000 for a three-month experiment depending on the mass of the necessary research materials which have to be sent up and we would have space for up to four experiments.

The Moon Base

Initial Construction

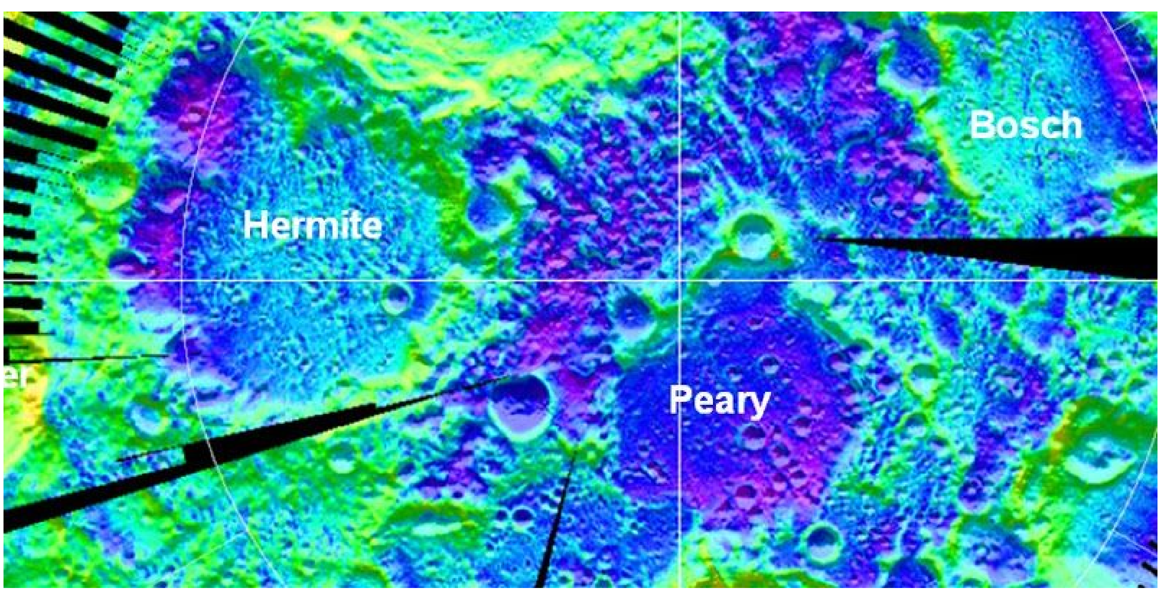
We thought about many different options when coming to a decision about the design of our Moon Base but decided to put it underground to shield it from the high levels of cosmic radiation and reduce damage caused by asteroid impacts, in the rare event that one occured. In order to minimise the number of materials that we have to transport to the Moon and thereby reduce costs, we have aimed to use materials found on the moon wherever possible. As much of the complex machinery and electronics as possible will be constructed on earth in order to reduce assembly time on the Moon, before bringing astronauts into space.



Construction will utilise both automated and remote-control robots. Once robots have completed the structure of the shell, the critical components, such as life support, will be sent up to the Moon and robots will finalise the base by installing as many of these components as they can. Later on, two astronauts will come up to the Moon to install the essential parts of the base (the bottom three pods and the life support systems). This should take at most three days and the astronauts can stay in the lunar rover during this period as it is a pressurized, radiation-hard safe haven that can sustain and protect exploring crew members for up to 72 hours. Once these essentials have been installed, the astronauts will live in the first three pods of the base whilst they and the robots complete the rest of the base.

The Location

We considered both the North and South Poles for our base location due to their believed proximity to water deposits. However, we finally settled on the North Pole and the Peary crater found at 88.5°N, 30°E for a number of reasons. Firstly it is a sufficiently large crater for our purposes (79km wide and 1.5km deep) with many craterlets in it, allowing us to build our habitation module in one of these craterlets and then cover it in lunar regolith to provide it with maximum radiation protection. Due to its position, it contains areas of almost permanent shadow in the southern part of the crater and yet around the edge (which is raised up) there are large areas of almost continuous sunlight. This allows us to have a constant source of energy from our solar panels and also gives us an extremely cold area (30-40K in the air and around 100K within the surface) to build the railgun and condense the silicon tetrafluoride. It is also thought that there are deposits of ice around the North Pole of the Moon giving us potential access to an easy water supply. In addition, it is believed that the denser deposits of tritium are more likely to be found in permanently shadowed areas of the Moon. This gives us a good chance of finding large deposits making our mining business a great deal more profitable.



A temperature map of the lunar north pole with purple being about -248℃.

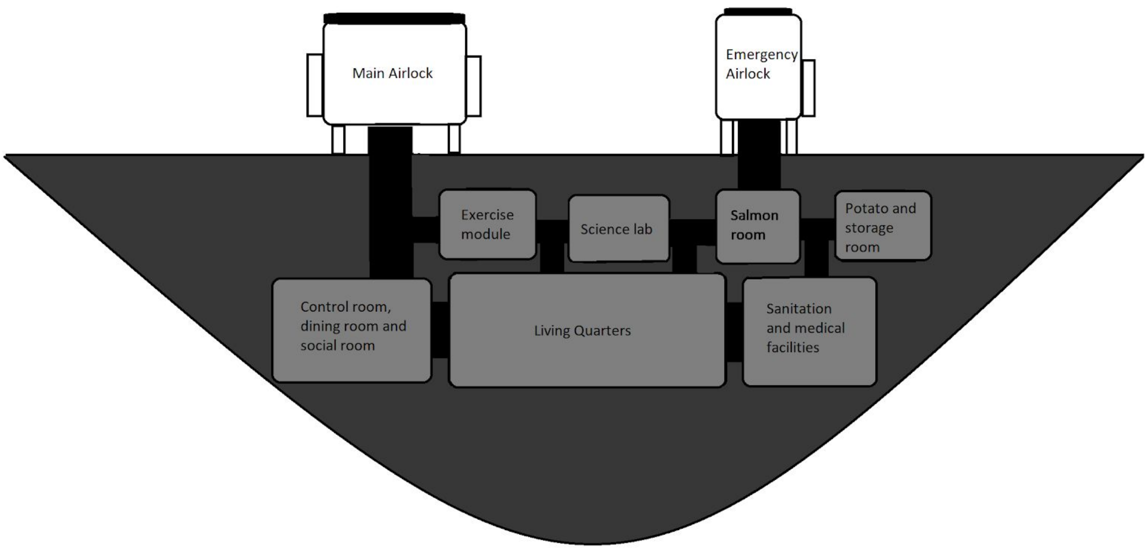
The Base

The Base itself will be constructed out of individual kevlar pods with metal struts for support running through the bulkheads. They will be pressure-sealed with a secondary kevlar ‘bubble’ surrounding each pod.

There will be an additional solid support from a 3D printed layer of lunar regolith surrounding it, acting as an exoskeleton. This layer will be formed by a Microwave Sinterator Freeform Additive Construction System (MSFACS) and the Athlete robot. The MSFACS takes solar energy and lunar regolith and uses the Sun’s energy to create microwaves by converting solar energy to electrical energy (as the photons from the sun excite the electrons in the silicon cells). This electricity could power a microwave generator in order to directly construct any basic shape. This is feasible on the Moon due to there being no atmosphere and because of the special thermal properties of lunar regolith. We will also use this 3D printing technology to create blast barrier walls around landing sites in order to protect the astronauts from the blasts created by landing spacecraft.

A 3D printed lunar regolith wall.

Our housing unit will be located within a craterlet in the Peary crater. The crater should be around 30m in diameter and 10m deep to fit the base underground. This is so the airlocks on the top of the base are level with the surface of the rest of the crater as the remainder of our base will be enveloped underground in lunar regolith. The sides of the crater need to be as shallow as possible and the base of the crater flat so that very little lunar regolith is needed to create a foundation below the bottom three pods of our base so they can all rest securely on the floor. Having flatter sides on the crater would also make it easier to put the pods in the crater. We will place the base in a part of the crater with light at some times of the day and darkness at other times in order to replicate the day-night cycle on Earth.



The housing is to be constructed in layers, with the areas where people spend most of their time (the control room, the living quarters and the sanitation and medical facilities) being deeper in the crater in order to give the astronauts more shielding from radiation. If one pod experiences a leak or threat of any kind, it will be sealed off after the inhabitants evacuate through the connectors to any of the neighbouring rooms. If necessary, the astronauts can then escape though either the main airlock (with two areas for rovers to dock) or through the emergency airlock (with only a single area for a rover to dock). The emergency airlock will only be used if completely necessary (if the main airlock fails or is inaccessible).

The rest of the crater will be filled with lunar regolith rubble, leaving only the airlocks above the ground in order to protect the astronauts from the higher levels of solar radiation. A secondary use for this rubble is that it can protect the base from micro asteroid impacts, which could cause damage to vital life support systems, and even puncture the surface of the base were it above ground.

Our lunar base was inspired by an ESA design and has a tiered design, using lunar regolith to provide insulation from solar radiation. In the design of our base we expanded the number of pods used to reflect the increased number of activities carried out at our base and made the pods rectangular rather than cylindrical to make construction easier. We also used a different airlock that is more practical as lunar rovers can dock there with ease.

Food

The bulk of the diet of the astronauts will consist of potatoes and fish, for the following reasons:

The fish and potato diet can be relatively self sustaining, with the fish faeces being used to fertilise the potatoes and potatoes can be fed back to the fish. As the astronauts will almost certainly become tired of a repetitive diet of entirely potatoes, fish will also be a part of the diet to combat stress and raise morale. In addition we will transport freeze-dried foods from Earth to be added to meals to raise morale such as dehydrated tomato sauce, pasta and many other additions to make the base diet less repetitive.

An especially important reason why these foods have been selected is that potatoes can provide the necessary energy for the astronauts, as they are very carbohydrate-dense, while the fish will provide the proteins and minerals that they need to build muscle mass. The potato farm will not have soil, but has extra nutrients pumped in with a filter into the water-based growth system. The filter then diffuses the essential nutrients, such as nitrates and magnesium, into the water brought up from Earth. The nutrients can then be recycled from both human and fish faeces allowing swift and sustainable nutrients for the potatoes' growth and therefore providing a reliable and substantial amount of food and energy for the inhabitants.

Minimal maintenance is required to maintain the farm, which means it is very efficient and cost-effective. In a weightless fish farm there may be a possibility of saving water, money and time by not having to keep the fish in water. On Earth fish die when they are removed from water due to the gravity pulling down on the fish's gills, causing them to collapse, so the fish cannot obtain oxygen. However, in space there is no gravity. On the Moon g=roughly $1.625ms^{-1}$ compared to $9.81ms^{-1}$ on Earth. As a result, it may be possible to have fish floating in a '0' G environment. However, more research can be done on this once we have set up our base. The cost of a fish farm itself, including the original fish, would be around £1,500 initially but it would then be very cheap to run. Ideally we would farm salmon as it is rich in protein and vitamins yet very efficient and relatively easy to farm as they grow quickly. There would also be no chance of parasites as they are in an isolated community, but on the other hand that leaves the fish more vulnerable to sudden illness. We would take the salmon up to the Moon as eggs and sperm to ensure survival.

Water

Water, as seen in the satellite images, can be found around the poles in ice deposits close to our Moon Base. This is to be our main source of water as it is extremely simple to mine and process, requiring no extra equipment and in addition is thought to be abundant.

Another idea was to extract water from the lunar regolith to feed our water needs. There are many ways of extracting water from the lunar regolith or straight from the soil with one of the main ways being that you can extract water from the regolith by adding hydrogen. The hydrogen reacts with the iron oxide in the moon rock to produce water. This would have to take place in hydrogen reduction reactors which heat the regolith to about 1,832 degrees Fahrenheit. However we decided that this method was not really viable due to the extreme temperatures and equipment needed to produce such little water.

A second potential method is to extract the small amount of water found in the lunar regolith as H_2O. On 18 August 1976, the Soviet Luna 24 probe landed at Mare Crisium and took samples from the depths of 118, 143, and 184 cm of the lunar regolith. These were returned to Earth for analysis. In February 1978, it was published that laboratory analysis of these samples showed they contained 0.1% water by mass. This means that in 1kg of regolith there was about 1 gram of water mass. Assuming that 1 person requires 2 litres of water a day, that person is using (183 days×2 litres) approximately 366 litres over 6 months. Weight = 1 gram. And Density = 1 gram/ml (or 1 g/cm^3). Then Volume = 1 / 1 = 1 ml. Therefore a single person needs 366kg of water. The water mass is 0.1%. So from the regolith this means that 366,000 kg of regolith will be required to supply a single person with enough water to drink for 6 months. This means that the option of only having water extracted using regolith is not feasible.

As a result, we have chosen to extract our water from lunar ice caps and also supply enough water from Earth, to support our crew of 20 for up to one month in case of emergencies. As one person requires 2 litres of water a day, this is 60 litres for a month's worth of water for one person. So for the entire crew we need 1,200 litres of emergency water.

In addition, as water on the Moon is a valuable commodity, we will install a complete water filtration system that will filter everything from urine to the water we breathe out as well as the astronauts' sweat. There is currently a similar experiment running on the ISS called the ECLSS water recycling system. Built by Marshal, this collects and filters all water losses to try to be as water-efficient as possible. The end product is water that is extremely clean and can be reused and recycled for everything. The filtration system mimics natural filtration on earth, using a multistage process involving machines that can be 100% controlled, instead of microbes. Water is passed through a coarse filter to remove any debris or particles before then being passed through the multi-filtration beds. These contain compounds to remove both organic and inorganic impurities. Finally the water passes through a catalytic oxidation reactor removing volatile oxygen compounds and killing off any bacteria or viruses that made it through, giving the end product of ultra clean water. However, this system is not 100% efficient, as it produces a small amount of brine which is unusable in any way.

The airlock suit systems will remove a small amount of air from the buildings and therefore we will lose a small amount of humidity, adding to our water losses.

The collection, filtration system is one way we plan to save on water usage and reuse our waste. We also plan to reduce the astronauts' water consumption as much as possible by lowering the water pressure in the base and insisting on washing with a damp washcloth.

In conclusion, we plan to reduce, reuse and recycle our water resources provided by the lunar ice caps as much as possible but we should always be able to gather more ice from the ice caps using our mining equipment. However, in the event of an emergency, we will have a small amount of emergency water stored away for use.

Life Support Systems

Heating:

Heat loss will not be a problem with no air convection to remove the heat. The problem will be attempting to remove built-up heat, as the 3D printed lunar regolith bricks covering our base will not only prevent damaging radiation from getting to the astronauts but will also stop heat from escaping. Unwanted heat from machinery and the astronauts' own bodies will build up in the atmosphere of the habitat. This is further compounded by the fact that lunar regolith is not a good conductor of heat. To combat this problem, we will be using a NASA-designed heat pump in order to circulate the heat for reuse in systems that require it. An example of this is the heated water system, to be used for cooking and washing with a washcloth, without which both sanitation and morale deteriorate quickly.

The heat pump uses a coolant (in this case ammonia) and four Mars rotary compressors, as well as heat exchangers in a system which is enclosed for health and safety reasons, e.g. astronauts touching hot pipes. The coolant will need to have a high specific heat capacity and be relatively non viscous as it will be pumped under pressure. For the coolants there are two main contenders which have been selected due to their ease of transport and low lethality to humans: ammonia and 1,1-Di-chloro-2,2,2-trifluoroethane, or R-123 for short. As a chlorofluorocarbon, R-123's use is banned on Earth due to negative environmental impacts on the ozone layer, but this restriction doesn't apply on the Moon as there is no ozone layer and the refrigerant will be kept in a completely closed system. Ammonia is also an attractive solution due to the fact that its leaks are self-alerting, that is to say, they have an extremely recognisable signature smell. In a less skilled environment this could cause minor panic, but the astronauts can be trained to recognise the problem immediately and deal with it rather than letting the gas spread and displace the air, which could lead to respiratory problems. The chosen refrigerant will be ammonia, due to its extreme ease of detection, which could also help point to other, more serious leaks. The coolant is then pumped around the system transporting heat from where it is in excess, to where it is required, in a safe manner.

Oxygen:

We plan to extract our required oxygen from lunar regolith using electrolysis and then mix it with nitrogen and argon brought up from earth. We will electrolyse molten calcium chloride which is commonly found in lunar regolith. When a current is passed through a graphite anode and cathode, with both electrodes in an electrolyte solution of molten calcium chloride, the electrical current removes oxygen at the cathode. Normally this oxygen is attracted to the carbon anode and produces carbon dioxide. However, if an unreactive anode is used, such as a mixture of calcium titanate and calcium ruthenate, then almost no carbon dioxide is produced and pure oxygen is released. This requires 4.5 kilowatts of power to operate and with 3 one metre tall reactors, 1 tonne of pure oxygen could be produced annually. Nitrogen, CO_2 and argon would also need to be brought up to the Moon with the initial load. CO_2 can also be produced in the electrolysis to make up air. This can then be distributed around the Moon Base to provide a good source of air for the inhabitants.

Logistics and Transport on the Moon:

We chose wheels instead of caterpillar tracks to allow for the more extreme terrain that tracks couldn't overcome such as the many steep-sided craterlets found in the Peary Crater. The wheels have a large amount of suspension to allow for the rough and bumpy surface of the Moon. They also have wheels made of cages so that they are lighter and don't have to be filled with oxygen. There are points for suits to attach to the exterior on both sides in accordance with our suit airlock plan, meaning no dust from the Moon enters the rover. The suits can be deployed from the side once the human is present and then easily reattached when required. This means no dust enters the rover and repairs or maintenance can be easily carried out while keeping the astronauts safe from the harmful effects of lunar dust.

The rover docks to the main Moon Base using a docking system that incorporates two interlocking plates, which rotate to close. This docking equipment also has charging cables running through the plates, which charge the rover whilst it is docked. The way into and out of the rover is then out the back, inside the docking plates, meaning no Moon dust, or dirt in general enters the rover, or the Moon Base at any point as it is a completely closed system.

The rover charges through the drogue, which is the cone-shaped apparatus at the top of the docking system shone. When this docks to the main Moon Base, it will automatically charge, ready for its next voyage.

Mass per Rover - 4000kg

Size of Rover - H 4m / L 4.5m / W 3m

Materials - The rover is made from aluminium and titanium which are lightweight so that transport costs are cheaper yet also strong and durable.

Max Speed - 12 m/s

Basic Rover Chassis with two astronauts riding on it

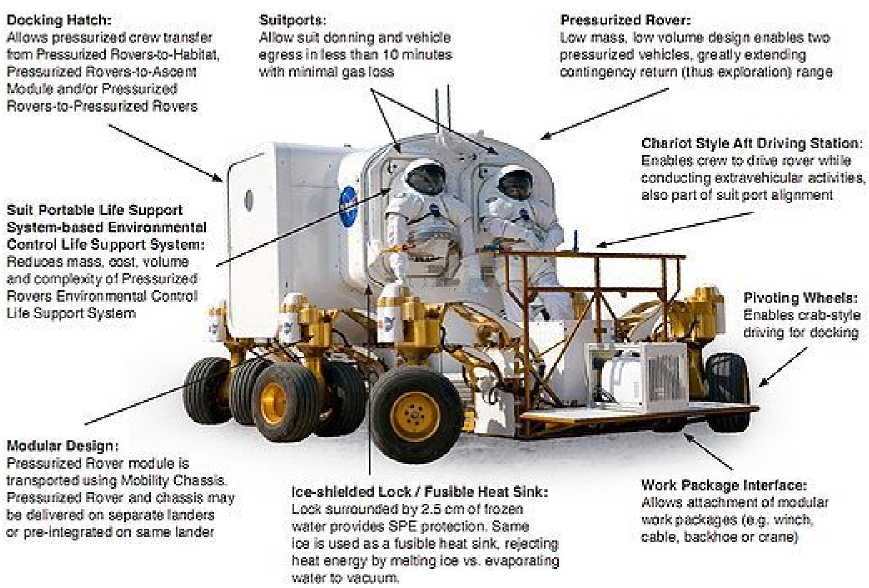
We will have two different types of rover built on a single chassis design allowing for easy maintenance and transferable parts.

The bulldozer rover:

We will use this in the construction of our Moon Base. It is based on the same chassis as the main lunar rover but has a bulldozer attachment on the front. We can use it to flatten surfaces for our different constructions and to push the lunar regolith into the crater once we have finished the construction of our Moon Base. Its mass is around 1.5 tonnes.

The transport rover:

The transport rover will be used for logistics on the Moon. It will transport parts and essentials around for construction and living on the Moon. It has a full life-support system and has the ability to support two astronauts indefinitely as long as they are resupplied. As such it has been nicknamed the lunar caravan and will be used to house the two astronauts initially constructing the basic Moon Base. Its mass is around 1.5 tonnes.



Energy

Overview of the Energy System

To power all of our Moon Base electronics we decided to use photovoltaic (PV) cells as they have the potential to be extremely cheap and efficient on the Moon. We considered using nuclear power but decided against it due to the more dangerous nature of fission and the fact that we are not yet capable of fusion. In addition, we might receive negative press coverage for using nuclear power on the Moon as it is seen as dangerous and toxic, whereas solar panels are viewed as green and clean. More specifically, we plan to use tandem junction amorphous silicon micromorph cells which have many benefits. Firstly twin junction cells are able to absorb more of the electromagnetic spectrum as they have twice as many junctions as single junction cells. The (PV) cells will absorb all of the visible light and some infrared and UV light that hits them. In addition, the micromorph layer significantly reduces the Staebler-Wronski Effect from a 25% loss of efficiency after six months to just 5%.

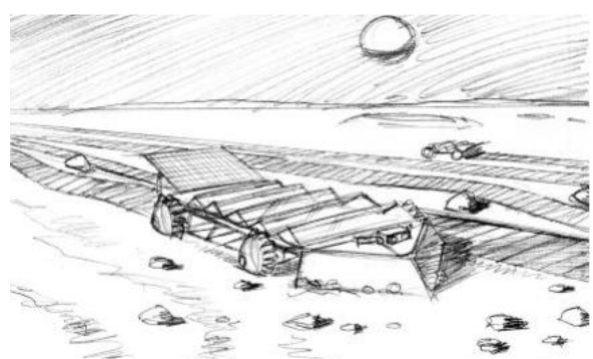
We plan to lay the solar panels using autonomous robots that produce the solar panels internally from silicon purified from lunar regolith. This comes with many benefits such as greatly reducing our transportation costs as we will only have to transport 'cell paver' robots, a solar oven capable of about 1025K, a condensing unit capable of 128K and the piping needed for our production of silicon tetrafluoride, as well as the materials we use to dope the PV cells and extract the silicon with. Furthermore, it provides our base with a near limitless energy supply as the outer edge of the Peary Crater is raised and so receives almost constant sunlight. In addition, our cells can be extremely thin due to the fact that there is no atmosphere on the Moon so they need little protection from wind damage or being covered in dust.

Production

To produce the photovoltaic (PV) cells we will first need to purify the silica in lunar regolith to form silicon.

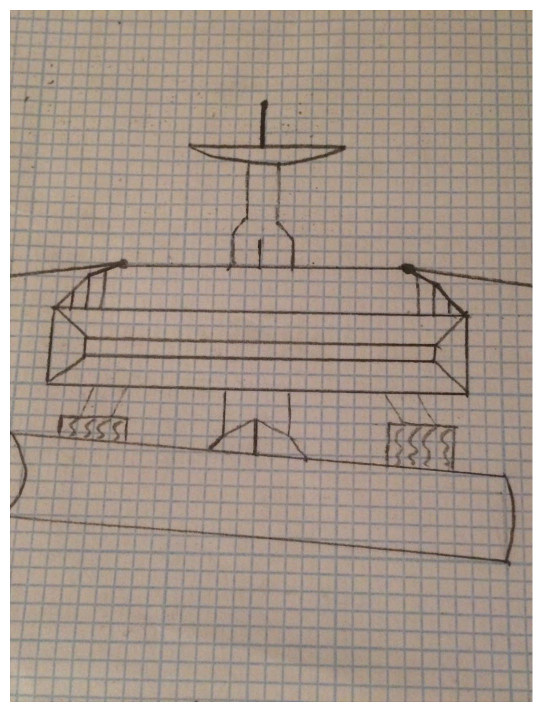
Firstly our mining industry will deliver unpurified lunar regolith to the purifying room. We will then electrolyze potassium fluoride in a eutectic salt to form potassium ions at the cathode and fluoride ions at the anode. This electrolysis process will require 10W of power and a solar oven heated to 710^{o}C. For the eutonic salt, we will use a 60:40 mixture of NaF:KF lowering the melting point from almost 1000^{o}C to just 710^{o}C. Then the fluoride ions will be reacted with lunar regolith heated to 500^{o}C in a displacement reaction forming SiF4 from SiO2 as well as byproducts of oxygen and metal fluorides. Then this silicon tetrafluoride will be condensed at 178K to separate it from the oxygen. This temperature can be achieved at our lunar base with little cooling needed. Then this silicon tetrafluoride can be pumped into the cell paver machines to be laid by plasma deposition. To reuse the byproducts of this reaction, the potassium ions can be added back to the metal fluoride formed when heating the lunar regolith with fluorine to form potassium fluoride (which can be reused) and pure metals such as titanium, iron and aluminium which can be transported back to earth. This requires a temperature of 500^{o}C. Oxygen can also be added to potassium and calcium fluoride to form calcium oxide and potassium fluoride at 550^{o}C. All in all, the requirements for producing silicon tetrafluoride are a solar oven capable of 710^{o}C, the eutectic salt, a condenser and some storage.

Then the silicon tetrafluoride is placed into the cell paver which is activated and autonomously lays solar panels. Firstly a glass-like substance will be made by directly melting lunar regolith at 1600^{o}C using small parabolic collectors and optical fibres to capture the thermal energy needed from the sun. This glassy substance has a resistance of 10^5 ohms which would allow the PV cells to be organised into a parallel circuit as they will not all be linked. In addition, this substance is extremely smooth with no features larger than 50nm protruding from the surface allowing for our PV cells to be very thin. This substance

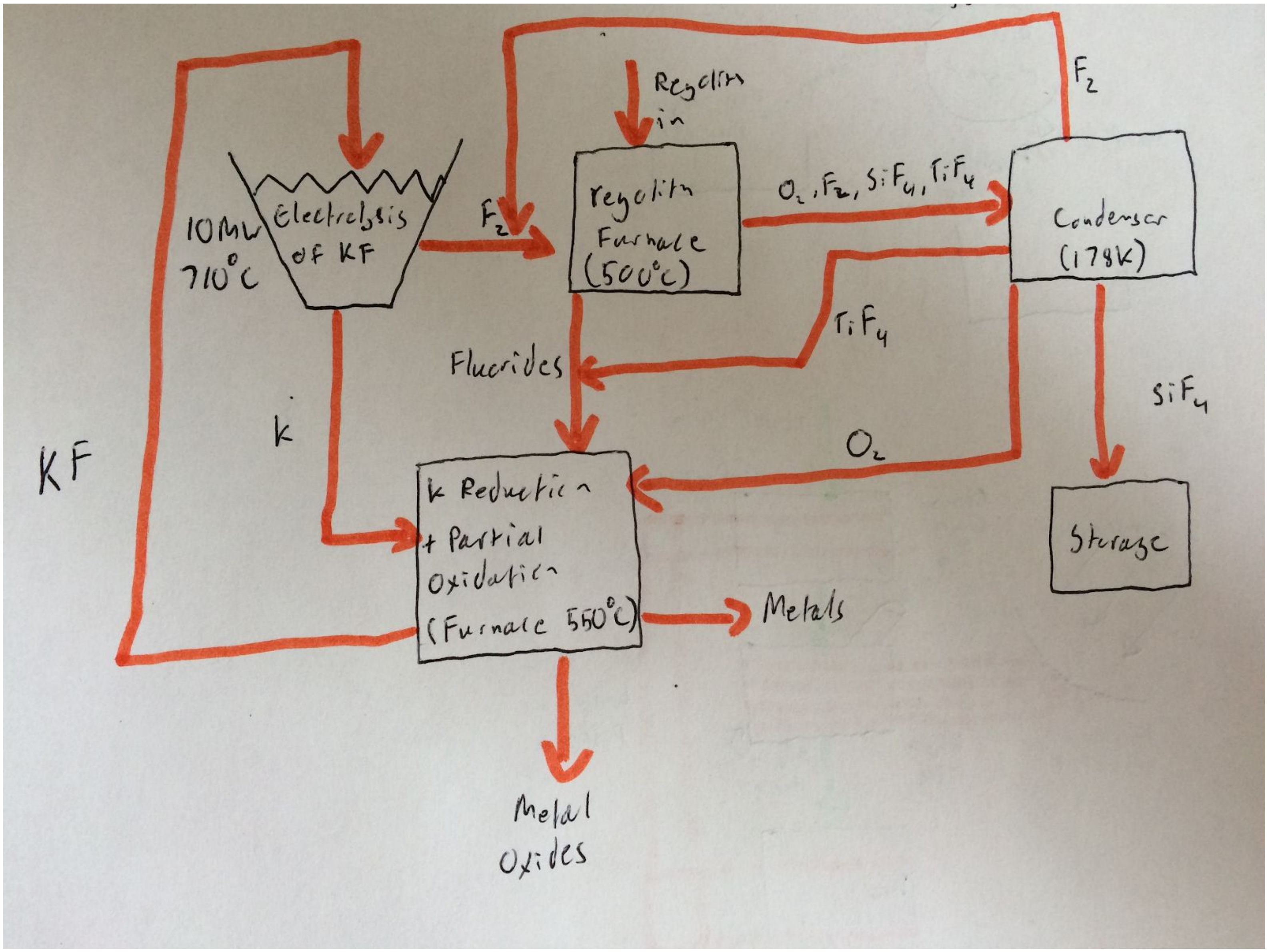


can also be deposited in very thin films and is almost as transparent as glass making it perfect for the substrate our silicon will be deposited on. Using a technique known as Plasma Deposition we will deposit an extremely thin layer of silicon onto our substrate coated in indium tin oxide, a transparent conducting film, which is slightly roughened to increase light trapping. This is done using 24GHz electron cyclotron plasma enhanced chemical vapour deposition to induce the silane hydrogen gas mix to become plasma. For the amorphous phase of production the silicon tetrafluoride to hydrogen ratio is about 1:1.5 which is then dropped to 1:0.9 during the microcrystalline phase.

The microcrystalline is on the bottom of the PIN diode structure allowing the cell to absorb more of the spectrum. This means that the micro crystalline layer has to have a thickness of about 1.5-2 μm whereas the silicon layer would have a thickness of 0.2-0.3 μm. This is so they both have similar currents, making the twin junction efficient. The cell would then be finished with an anti-reflective coating similar to the phenomenon observed in moths' eyes and used by Canon in their cameras. Finally the robot can lay the electrical connections needed to wire the cell in parallel.

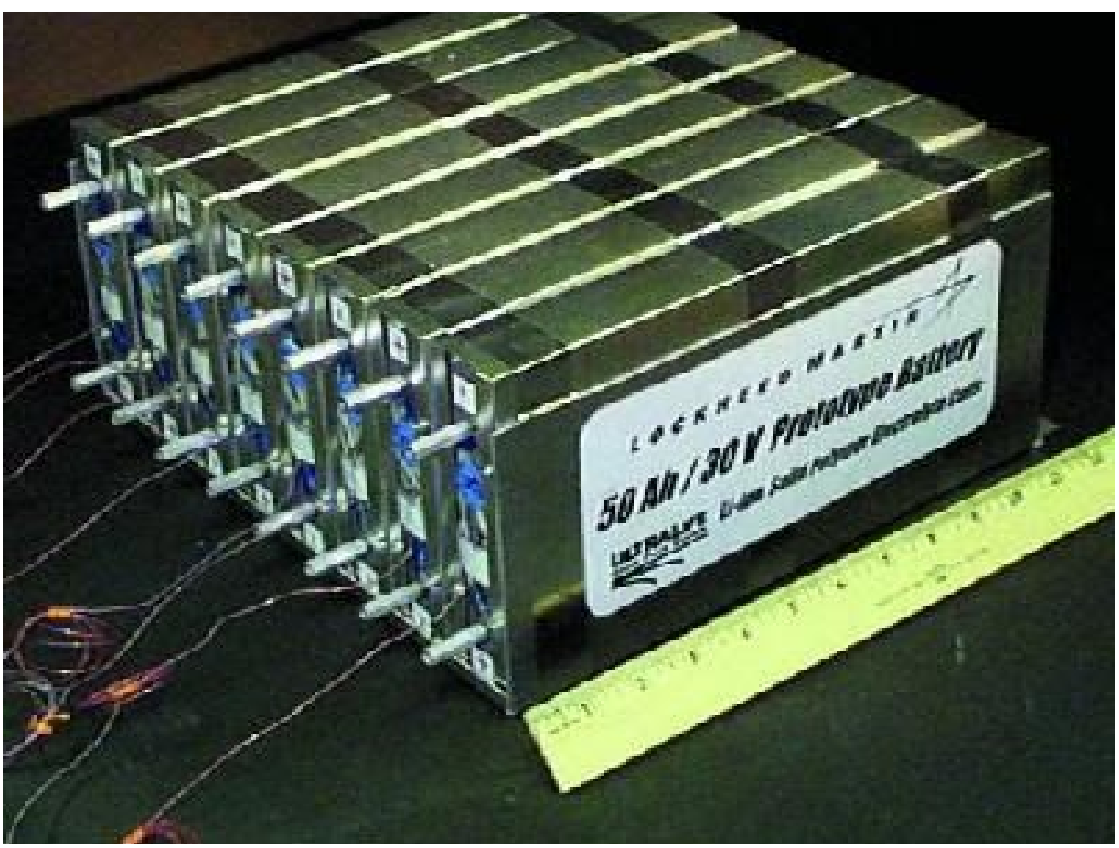


The cell paver will be a rectangular robot with a 1m squared solar cell to power it and a range of sensors and claws on the outside to aid in its path selection. On the inside it will house the facilities needed for Plasma Deposition and it will carry all the materials it needs to lay PV cells. Its sensors will allow it to detect obstacles, dips and shadows to help it choose the most efficient route to lay its cells. It can then use its bulldozer and claw attachments to try to make a flat path to lay solar panels on. However, if that is not possible, it will find its way around the obstacle as shown in the image. It will be completely autonomous but there will be two managers who will oversee all of these robots. Another role these cell pavers can perform is cleaning the solar panels of any dust or debris from micro meteor impacts.


Regolith in
Electrolysis of KF
10MW
710°C
F2
regolith Furnace (500°C)
O2, F2, SiF4, TiF4
Condenser (178K)
F2
TiF4
Fluorides
SiF4
k
KF
O2
k Reduction + Partial Oxidation (Furnace 550°C)
Storage
Metals
Metal Oxides

Storage

We will need a large amount of battery storage as we will require a large amount of energy. The railgun will be on a completely isolated electrical system from the Moon Base to allow us to easily switch it on and off. If it malfunctions, it will not affect the safety of the astronauts. As it requires so many joules in such a short amount of time, we will store the energy for it in high capacity capacitors which can discharge at an extremely high voltage three times a week. The Moon Base has an energy consumption of roughly triple that of the ISS so, for redundancy, we will use four times the battery storage. This means we will have 100 lithium ion batteries which each weigh 150kg totalling 15,000kg of batteries. These batteries have a very high charge density (twice that of the old nickel hydrogen batteries) and very high recharge cycle count meaning they will not have to be replaced for at least ten years. In addition, the impact of aging will be lessened due to the fact that they are being stored at very low temperatures of 40K. Our solar panels being laid in areas of near constant sunlight means that we will not have to rely on battery power for more than approximately one week a year.



Calculations

Our outer atmosphere receives 1,367Wm^{-2} based on a yearly average and since there is a vacuum between the outer atmosphere and the Moon I have assumed that the Moon receives the same amount of energy. It is estimated that our solar panels could have a maximum efficiency of up to 22%. However, due to the Staebler-Wronski Effect acting over time, I will reduce this to an average of 18% efficiency.

$$1367 \times \frac{18}{100} = 250$$

So we capture 250Wm^{-2} with our tandem junction amorphous silicon micromorph cells.

Our total power requirement for the entire base is 455,400W. However, we need to factor in redundancy of 75% which is 796,950W. We can divide this by the amount of power our PV cells produce per meter squared to give us the area of solar panels required to produce the power for the base in meters squared.

$$\frac{796950}{250} = 3188$$

So we require 3,188m^2 to power our base's activities. This is 0.003188Km^2.

The Future of Energy

In the future, the efficiency of our cells could become more of an issue due to the Staebler-Wronski Effect and the amount of space we have already taken up with solar panels. So to make our PV cells more efficient we could layer cells on top of each other. This is possible because of their thinness which makes them transparent so EM radiation will still reach the lower cells.

Another way of reducing the Staebler-Wronski Effect is to anneal the PV cells at 150^{o}C. However, this would require other automated pieces of equipment. These could be developed and brought up later if needed. We estimate that in the first ten years of lunar living, we will be able to produce enough power by expanding the area that our solar panels cover. At some point in the future our energy demands will increase beyond a reasonable amount for these cells to produce and it will become necessary to increase their efficiency. When these issues arise, it is likely that there will be solutions. For example, there is a chance that the Staebler-Wronski Effect could be overcome entirely. Finally, to increase our maximum energy production, cell pavers can be working continuously (we will bring four to start with). If that rate of expansion is not enough, then we can ship more up to increase productivity.

General Health

To prevent bone and muscle mass loss, the astronauts will have a one-hour session each day during which they will exercise in a dedicated fitness room. The room will contain a set of four specially designed lunar treadmills and four lunar fitness bicycles, as well as a set of 'weight' machines and crunch machines. These machines simulate weight using rubber bands to minimise the chance of injuries such as a slipped vertebra disc, which would be difficult to treat on the Moon.

The room itself will be formed by the connection of two 3x3x3 unit bulkheads which will be easier to manufacture as part of the en masse manufacturing processes used to make the other bulkheads and connectors.

We will also use a treadmill record measurements such as blood pressure while exercising and heart rate to set astronauts physical challenges keeping them fit.

In order to simulate weighted exercise we will use adjustable springs to give the resistance required as modeled by this astronaut on the ISS

The exercise routine will consist of gradually adding workload rotated between machines to ensure that all muscles, including the core, will be exercised. To start, the astronauts will spend twenty minutes at a light to medium pace on the bicycle to get them warmed up. They will then sprint for thirty seconds with thirty seconds' rest directly afterwards on a treadmill, which will be repeated five times. They will then do 10 squats pulling up a 100N 'weight', 10 squats pulling up a 200N 'weight', and finally 10 squats pulling up a 400N 'weight'. We will limit missions to six months as reduced gravity leads to your spine extending as the weight pushing down on you is less than on Earth.

Mental Health

As the astronauts may suffer from homesickness, the walls of the astronauts' rooms will have a wide screen, curved television displaying long but repeating clips of the country that they are from to sustain positive mental health over prolonged periods of time. To combat short-term stress build-up, a recreational area and designated time of 'day', to be changed using mood lighting, will be provided as a more subtle method of boosting morale for the crew members. The recreational area itself will contain a table tennis table, a table for eating and board games, and a video gaming console, the most viable option for which is the Nintendo Switch, due to its portability and the range of entertainment available.

The astronauts will likely grow tired of working with the same people for months at a time, so crews will be rotated to and from the Lagrange point station and the actual Moon Base every three weeks, with crews being rotated back to Earth to see friends and family once every six months.

While training the astronauts in a team, they will be tested to see if they are 'compatible' with each other. They will be kept in a cramped and ideally stressful environment together, likely under the guise of a test to see performance following a leak, during which they will have to remain fully cooperative with each other in order to fix the problem. Should this be completed too quickly, another impossible problem will be presented (although the astronauts themselves will not know this) as a way to keep them together for the duration of the test.

The Transport System

The Starship

We chose the SpaceX Starship because of its comparatively inexpensive launch cost, high cargo capacity and fully reusable design which puts it well ahead of other competitors.
It is projected to achieve an orbital flight within the year and a flight with a manned cargo by 2025 which is relatively soon compared to other options of a similar type.

When choosing our main transport system, we considered other means of propulsion such as ion thrusters and plasma engines. However, we decided that they were unrealistically far from being reliable by 2030, whereas rocket engines are already tested.

We decided our rocket needed to be reusable and to be as economical as possible as well as being able to carry extremely large loads of up to 100 tonnes or more, to enable us to carry all our cargo in as few trips as possible. It also needed to be able to carry astronauts comfortably with very little adaptation to make it viable.
We calculated that a rocket meeting these criteria would be most cost-efficient per launch.

We considered rockets such as the Vulcan which was discounted due to it being unlikely to be available by 2030. We also looked at the Delta IV Heavy but decided it was more expensive per launch and could carry less than the Space X Starship as well as the fact it wasn't designed to carry people. As a result we chose the Space X Starship with a Falcon Heavy as its booster rocket.

The Starship is made up of two sections; the starship part in the top of the photo above, which contains the crew and the cargo used in lunar travel and the super heavy booster rocket to propel the starship out of earth's atmosphere (shown breaking off in the image).

The Starship is powered by six raptor engines and its Super Heavy launch booster is powered by 37 of these engines. After launch and when at the correct altitude, the Super Heavy booster rocket will break off from the starship and return to its launch point ready to fly again with minimal adjustments. Meanwhile the starship can continue onwards, self-propelled and refuelable. The starship has a 100 metric tonne cargo bay which is the largest of its kind, allowing us to transport many pieces of useful equipment along with over 100 astronauts if needed.

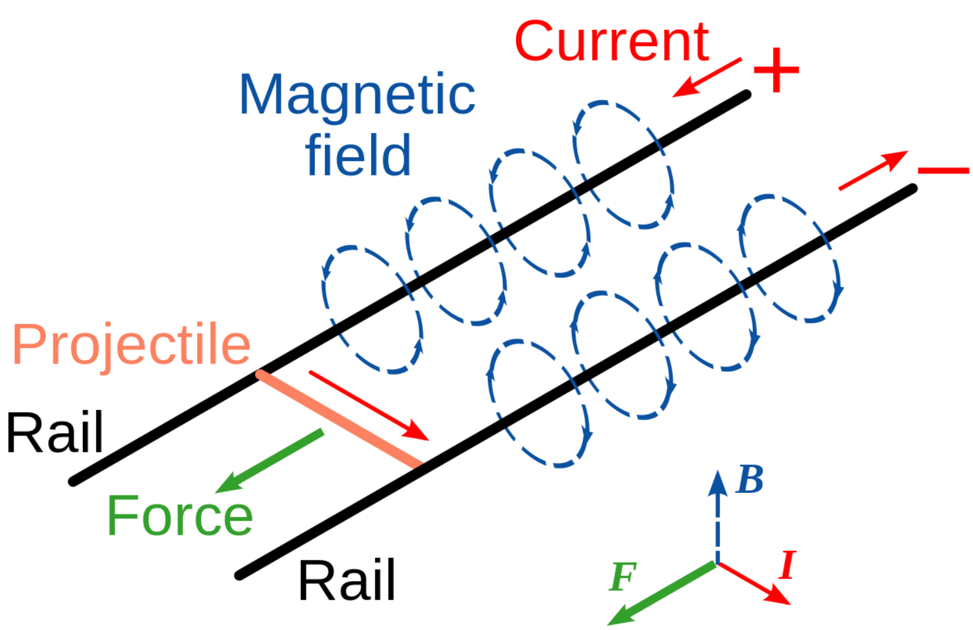
The raptor engines used to power this vehicle are newly designed state of the art engines which each provide 2MN of thrust. They have a 1.3m diameter and are 3.1m tall and are powered by a mixture of liquid oxygen and cryogenic methane. This liquid propellant mixture allows for a highly effective oxidising agent which isn't as toxic or reactive as other liquid options. Although there are difficulties with the storage of this fuel as it needs to be stored at low temperatures, it provides a cheap and relatively light way to fuel the rocket. This results in a total fuel cost of only $900,000 a launch meaning in total it only costs $2 million a launch.

The Railgun

For our commercial activity we need to transport a large amount of material back to earth from the Moon in order to make our mining business economically viable. The solution that we have decided upon is a railgun. This railgun will be capable of launching 5 tonnes of material from the lunar surface three times a week.

A railgun works by having two parallel, oppositely charged, rails.The charge in these rails is created by flowing extremely high currents through them. The projectile, held within casing referred to as the armature, will also have a magnetic field generated around it. The important factor is that this magnetic field will be perpendicular to the fields generated around the two wires. This creates repulsion and a force upon the armature pushing it down the rails, accelerating it rapidly until it is expelled from the railgun.

The image below, is taken from an example of a military railgun design that is to be implemented on naval vessels in the US Navy.



The faster these projectiles need to travel, or the more mass the projectiles have, the more force is required because Force=mass×acceleration. This means that a stronger magnetic field will be required and in turn, a greater current.

The first thing to ascertain was the escape velocity from the Moon. As there would only be this initial propulsion, it would accelerate as it leaves the Moon's gravitational field before accelerating again once reached the influence of earth's gravitational field. This can be calculated by a series of equations.

Firstly:
$KE_1+GPE_1= KE_2+GPE_2$

This can be assumed because of the law of conservation of energy.

At an infinite distance, the gravitational potential of a mass will be equal to zero and due to the infinite deceleration the kinetic energy will also be equal to zero at an infinite distance.

The equation can now be rearranged to:
$KE_1+GPE_1= 0+0$
$KE_1= -GPE_1$

The GPE is attractive therefore and equal to $-GMm/r$ where:

G is the Newtonian Gravitational Constant: $6.67\times10^{-11}m^3Kg^{-1}s^{-2}$

M is the Mass of the Moon: $7.34767309\times10^{22}Kg$

r is the radius from the centre of the Moon: $1737100m$

m is the mass of the object which is inconsequential

The KE is equal to $0.5mV^2$ where:

m is the mass of the object which is inconsequential

V is the escape velocity:

$0.5mV^2 = GMm/r$
$V^2 = GMm/r0.5m$
$V^2 = GM/0.5r$
$V = \sqrt{2GM/r}$
$V = \sqrt{2(6.67\times10^{-11})(7.34767309\times10^{22})/1737100}$
$V = \sqrt{(2(6.67)(7.34767309)/1.737100)\times10^{5}}$
$V = 2375.42ms^{-1}$

Knowing this final velocity we can now calculate the acceleration required to reach this from a standing point and then calculate the force required as we know the mass.

s = Length of Rails = 45m
u = Initial Velocity = $0ms^{-1}$
v = Final Velocity = $2375.42ms^{-1}$
a = Acceleration = ?
t = Time for Acceleration = ?

$v^2 = u^2 + 2as$
$(V^2 - u^2)/2s = a$
$(2375.42^2)/ 2x45 = 62696ms^{-2}$

$s = (u+v)t/2$
$(2s)/(u+v) = t$
$(2\times45)/(2375.42) = 0.03788s$

This value for acceleration is very high in normal terms but in terms of a railgun these values are to be expected. The force acting on the armature is very high as a result of this. The value for the force can be easily calculated using Newton's famous equation:

$F = ma$

F = The force acting on the armature = ?

m = Mass of the armature (regolith+vehicle) = 5000Kg

a = Acceleration of armature = 62696ms^{-2}

$F = 5000 \times 62696$

F = 313,478,899N

This value for force can then be used to calculate the current required down the rails using the railgun equation.

$$\mathbf{F} = I \int_r^{d-r} \mathrm{d}\boldsymbol{\ell} \times \frac{\mu_0 I}{4\pi}\left(\frac{1}{s} + \frac{1}{d-s}\right)\hat{z} = \frac{\mu_0 I^2}{2\pi}\ln\left(\frac{d-r}{r}\right)\widehat{x}$$

F = Accelerating force = 313,478,899N

I = Armature Current = ?

μ_0 = Permeability Constant = $4\pi \times 10^{-7}$

d = distance between central axis of rails = 3m

r = radius of the rails = 0.2m

The xˆ just refers to the force acting in the x direction so doesn't have a value

$$313,478,899 = \frac{(4\pi \times 10^{-7}) \times I^2}{2\pi} \times Ln(\frac{3-0.2}{0.2})$$

$$1,969,646,012 = (4\pi \times 10^{-7}) \times I^2 \times Ln(\frac{3-0.2}{0.2})$$

$$1.567394495 \times 10^{15} = I^2 \times Ln(\frac{3-0.2}{0.2})$$

$$5.9392210842 \times 10^{14} = I^2$$

$$I = 2.437 \times 10^7 A$$

Due to the scale of this railgun, there are some important considerations to take into account. The current required would be incredibly high and resistance in normal wire would result in massive heating, followed by cooling, which would accelerate the wear of the rails dramatically.

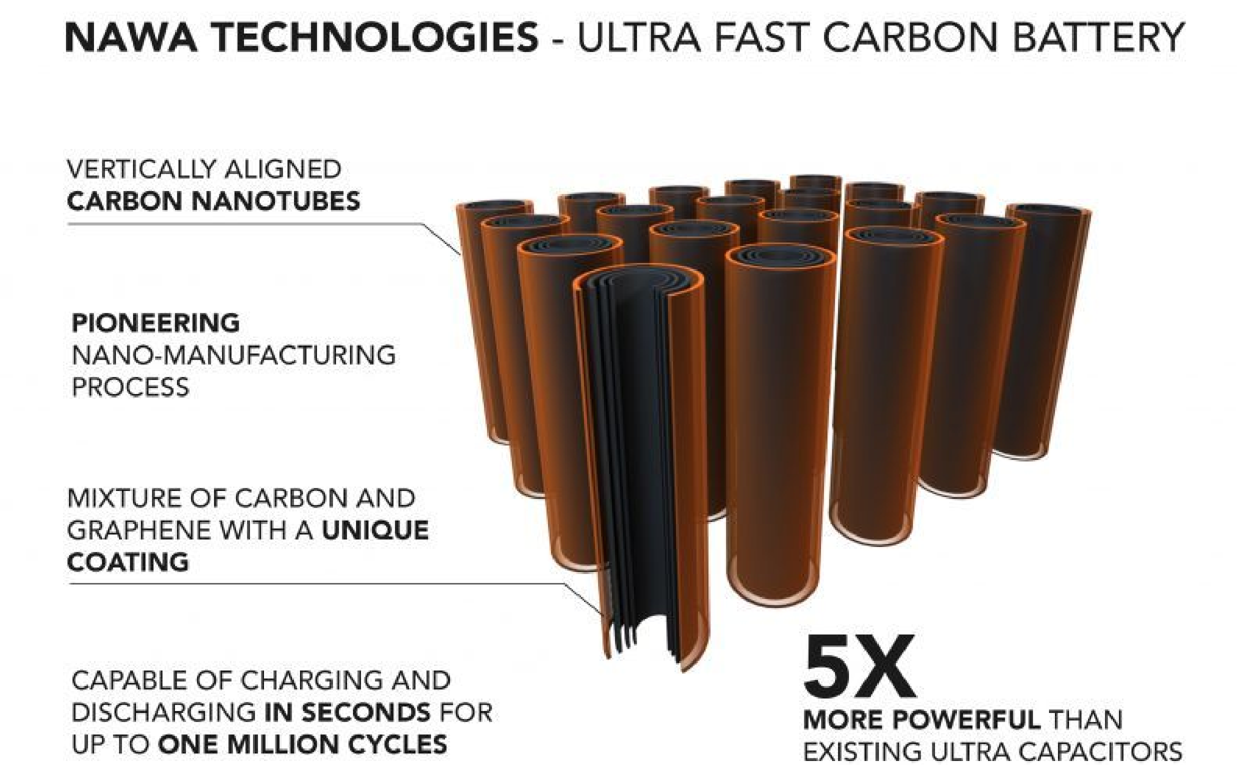
The way I have found to combat this is the use of superconductors. This technology is becoming increasingly commonplace and is hugely beneficial, particularly with devices like this railgun which would be impossible without them. The reason that superconductors are useful is they have such a low resistance that it is effectively negligible. The problem with them, however, is that they must be at a certain temperature to work. This temperature is always low but, after some research, I was able to find a superconductor which functions at the temperature I would be dealing with in the crater, where our lunar base is going to be located.

The compound is $HgBa_2Ca_2Cu_2O_{8+\delta}$ and it functions as a superconductor at temperatures between 133K-138K which would be relatively easy to maintain on the lunar surface. The problem I now face is the production of enough of this material to make two 45m long tubes that are both 40cm in diameter. This material has only been made in a laboratory in batches of around 0.7g. However, the synthesis conditions of 785^{o}C-800^{o}C are simple to replicate on a large scale. Annealing the large volume of material required for this railgun would take around a year. This process would run concurrently with all other preparations for the launch.

This current will be being released by capacitors as it needs to be delivered in a very small amount of time in order for escape velocity to be achieved. When it comes to capacitors though, the calculated required value is said to be only 70% of what will be required in a realistic scenario. Using this rule, I arrive at a final value of a current required of 3.6×10^{7}A, for 0.037s

After research and consultation with people who have experience in the field, I have decided upon using ultracapacitors that use the same technology as those created by NaWa Technologies. The special property of these capacitors is that they are composed of carbon nanotubes aligned vertically which allows them to discharge in seconds into a normal circuit which, although it is thousands of times faster than a normal battery, isn't fast enough for the railgun. However, as they are discharging into a superconducting material, it means that it can transfer the charge with a great enough speed to propel the projectile at the escape velocity.

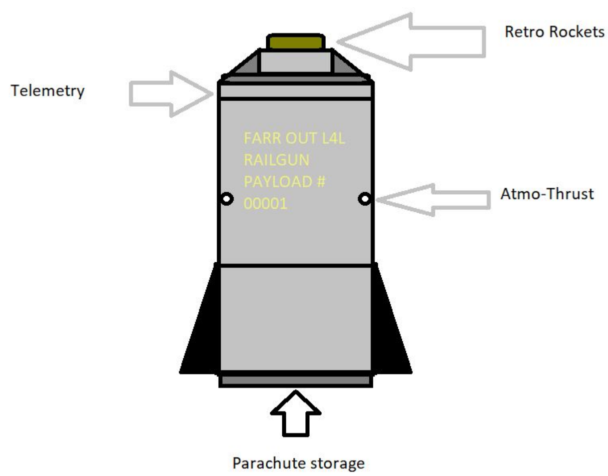
There are still important factors to take into consideration when dealing with the railgun, however. One of these factors is the heat generated by the sudden compression of air in front of the projectile. This is a massive problem with earth-based railguns, particularly military ones. This is not a problem in this situation because, whilst the Moon does have what could be called an atmosphere, it has a pressure of 3×10^{-15} Atm so it is entirely inconsequential.



A second issue is something that I do have to take into account, even on the Moon. In order for the armature to have a current flowing through it, it needs to be in contact with the rails as it accelerates. This is something referred to as point contact. The benefit of only having a tiny point touching is that it drastically reduces friction. On the other hand, the interface between two superconductors does result in resistance. With extreme currents this will result in the metal melting and this will cause friction in the launch, which will be small but should still be accounted for.

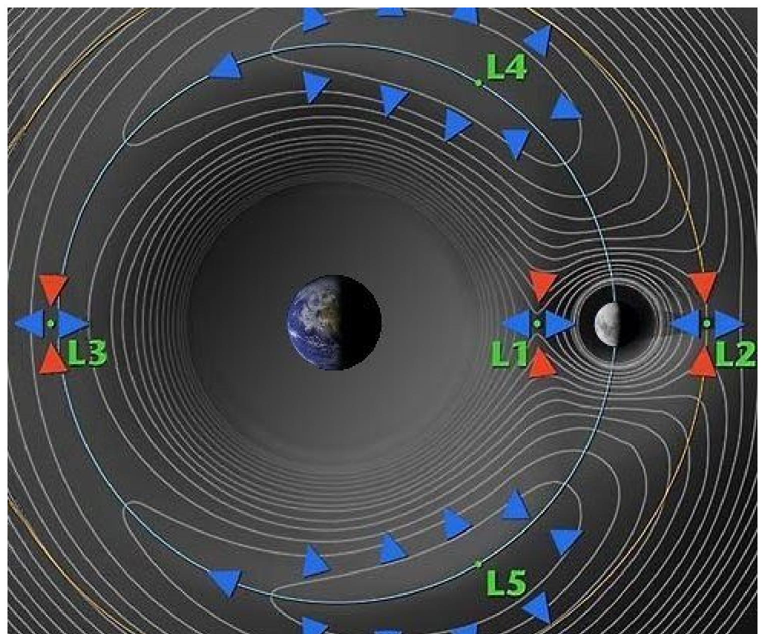
Initially one of the materials that we thought could be mined and transported from the moon was going to be lithium. This was rejected as an idea after we concluded that the railgun would be our method of transfer. The issue is that lithium is a reactive material and with the extremely high acceleration of the craft carrying the mined material, if there was a high concentration of lithium then it would be prone to igniting and destroying the entire craft.

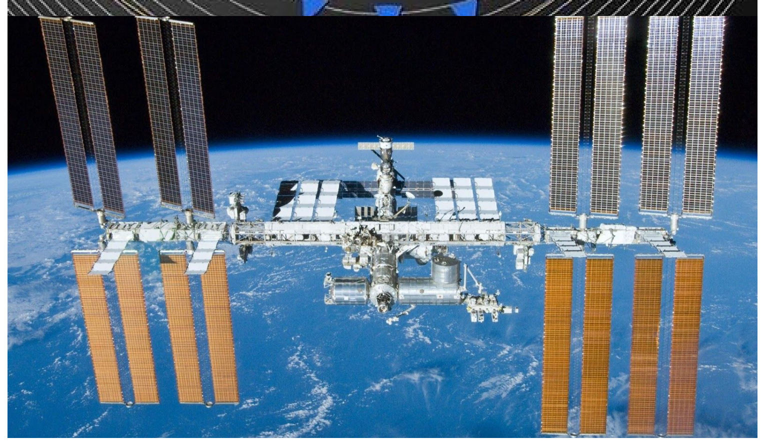
The payload that will be sent back to the Earth is a small craft with some ability to change course while in space due to its atmo thrust. It will be precision-landed, first by the retro rocket mounted on the front to slow it into the right earth orbit, and then with a parachute that will slow and stabilize its descent through the atmosphere.



The Space Station

We plan to break in two the journey from earth to the Moon Base by placing a space station in a stationary orbit at a La Grange point in order to reduce costs and fuel usage. This station can also act as a communications array and a break of routine for the astronauts.



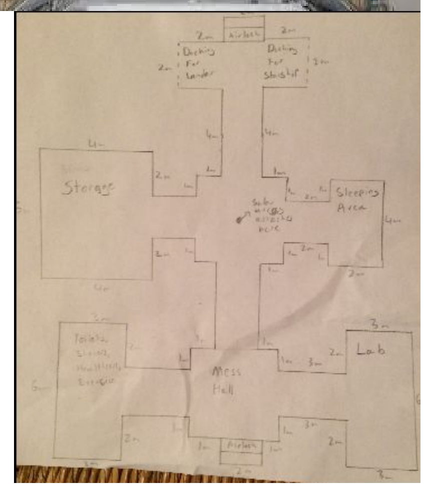


The space station will be constructed by sending individual modules to the La Grange point over a two-year schedule. First up will be the central hub module as that will connect to four different modules. Next up is the mess hall and docking hub, the docking hub going up as it is the most important so any deficiencies can be ironed out before the station becomes fully operational. The mess hall is sent up due to the fact that it will be connected to two other modules. Next up will be the storage unit to store potential supplies for maintenance, then the sleeping unit, so astronauts can potentially do onsite repairs on the station whilst staying on board. The hygiene and exercise quarters will be up next, and finally the lab as it is the lowest priority part of the station.

Our space station will be placed at a La Grange Point, which is the point where the gravitational forces of 2 large bodies balance out meaning there is almost zero resultant force due to gravity felt at these points. This allows us to build and place a small space station at these points as NASA has done with the WMAP. We will use L1 as marked on the diagram to reduce the initial distance traveled by the Starship.

L1 also has the added benefit of still being within the protective influence of earth's magnetosphere for most of the time meaning it is shielded from the magnetotail and plasma sheet which can have harmful effects on humans.

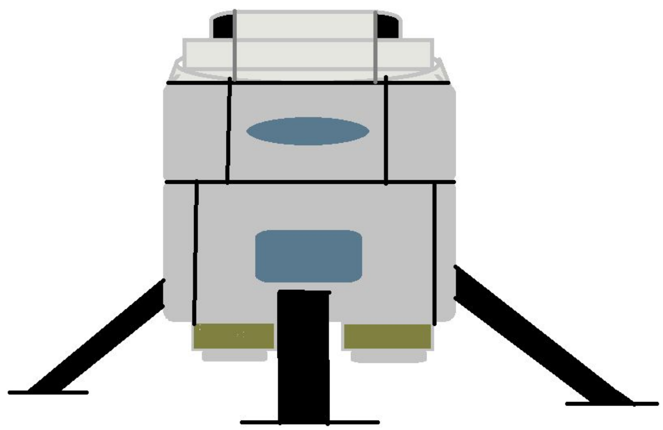
The primary use of this permanent base will be to provide a transit hub between the earth and the Moon. The station will be permanently manned as its stationary orbit isn't perfect. Since it is on a saddle point, it will require active station keeping. It will be constructed prior to humans landing on the Moon so that it can then be used as a forward base to oversee the construction of the lunar base and as a communications array for the Moon Base. The station will have a permanent crew of four people, but can sleep up to ten for transit purposes. It will also be able to conduct microgravitic research similar to the ISS as there will be a lab permanently on board. A further purpose of the space station will be as a first responder in case of a failure of equipment or loss of light on the lunar surface. As it is so close to the Moon, it can act to repair ships, respond to emergencies or become an emergency evacuation point for a short period of time. It operates on a completely different electrical system to the Moon Base so would not be affected by any failures that could occur. In terms of modules on the station, there will be a docking hub for the lunar descent vehicle to attach to as well as the starship. There will also be a sleeping station, with sleeping closests on all walls and ceilings and the floor which open up for when astronauts want to sleep. In addition there will be a storage area which can store everything from supplies and materials necessary for station repairs to parts of the Moon base that are being sent up to the Moon to be replaced. There will also be a mess hall module, a lab for the permanent crew to conduct research in, and a module that will have a toilet and exercise equipment to prevent loss of muscle mass in a zero gravity environment. This will also leave a necessary amount of muscle mass for normal activity on the lunar surface as a part of their rotation as part of the active crew on the Moon. The exercise will consist of one hour of cardio (treadmill) and an hour of strength training, similar to that of the ISS. The reason for the low astronaut



count on the space station is that it is not very large and is only designed to hold many passengers if a critical emergency occurs on the lunar surface. The energy requirement for the space station is 60000W. We have decided to use the ISS arrays for power generation because there is ample redundancy, and the number one thing that goes wrong on the ISS is that the solar panels fail and have to be fixed. As this station is much further away from earth and will not be able to receive as many supplies, the more redundancy in the panels the better. The space station can hold the entire lunar crew for short periods of time in case of critical failure on the lunar surface, when they will be evacuated as quickly as possible, and returned to the station where a starship will be able to return them to earth. However, there are enough supplies to last only a few days in case of complications, meaning that either the spaceships can’t launch or some of the crew has not returned to the station. The station will also act as a full-time communications link between the lunar base and the earth meaning that there will never be a point with comms ‘going dark’. It also means a larger comms array can be used as it will be in space rather than having to land an array, which is more likely to go wrong.

The Lunar Park and Ride

The Lunar Park and Ride will be the specialised descent vehicle between the station and the Moon Base, and will be powered by a dual hydrazine combustion rocket engine. The reason for using hydrazine is that it can be stored on the lunar surface as a solid, Hydrazine Hydrate. This non-volatile substance can be quickly converted into hydrazine ready for the park and ride modules, enabling astronauts to be evacuated or transported off the Moon to the station. The ascent vehicle should be able to take half of the crew off the lunar surface at once, with a second ascent/descent vehicle stored on the Moon next to the base in case of failure. This can also be used to make sure all of the Moon crew will get off the surface in case of catastrophic system failure on the Moon. Doing all its refuelling on the lunar surface, the vehicle will be primarily stored there, as maintenance will be easier to perform, and less dangerous. The vehicles are designed to take ten passengers the short distance from the Moon to the station, and maybe a small number of scientific samples such as moon rocks to sell to labs and universities, but not much more than 200 kg.They can also transport a large amount of data kept in solid state drives, which are the most effective way to transport data due to the robustness of the modules and the high storage to volume of them. The capsule is designed to dock to the space station in a custom dock, where it will attach to the space station. This will allow all the astronauts to get onto the space station. The interior is two floors of five seats each with a central ladder allowing passengers to move through the vehicle.



The space station will be approximately 60,000km from the lunar surface and so the vehicle will only take 4h to get there and 6h to go to the lunar surface due to orbiting patterns and descent. The lander has no fins and a lack of aerodynamics due to the fact that it will not be coming into contact with any atmospheric resistance. Astronauts will enter the hatch in their flight suits (which are less bulky space suits with minimal life support systems, only designed to be worn on ascent or descent).

The Logistics and Economics

	Mining	Energy	Railgun	Food	Space Station	Habitation	Transport
Mass (kg)	300000	160000	180000	200	205000	35000	10500
Power (W)	64000	5000	74500 (3 launches a week)	2900	60000*	155000	5000

*The space station is powered by its own set of solar panels

Mass

As shown in the table above, the total mass of everything which we will need to send up into space is 890,700kg. However, we need to add in a redundancy factor of about 75% (to make certain nothing can go wrong) which takes the total mass to 1,560,000kg. Since the Starship has a 100,000kg cargo bay, this comes to 16 rocket launches which will be spread as shown in the flowchart. As the Starship should cost $1,500,000, a launch that comes to a total cost of about $24,000,000 for all of our rocket launches.

Economics

Component	Cost ($-millions)
Mining	200
Solar panels	100
Railgun	100,000 (100bn)
Food	8
Space station	100,000 (100bn)
Habitation	1,000 (1bn)
Transport on the Moon	50
Transport to the Moon	150
Salaries	23 per annum (maximum)

Reasoning behind the cost:

Mining: One of the main reasons why mining costs so much is the custom mining robots which will be very expensive to produce, and also have very high mass and so will be costly to send up to the Moon, due to the size of them.

Solar Panels: The solar panels could and would be more expensive if we were to ship them up but, due to the fact that we are sending a solar panel fabricating robot to mine and refine and then eventually lay the panels, not only is there less of an impact on the earth as nothing will be refined there but there is also room for expansion. The main cost will come from the production of the robot and sending it up there.

Railgun: The primary cost of the railgun is the production of superconductors in the railgun which have only ever had a few grams produced, so the two 45m-long conducting rails weighing multiple tonnes each will have a ridiculously high cost. Also the cost of sending the rails up will be very high due to the fact that they will have to be assembled on earth and so will require specialised launches. Next, the cost of sending payloads to the Moon and of producing those payloads will be expensive, as will the constant upkeep of repairing and refitting the pre-launched ones when they break after time. However, it should be possible to get many uses out of them. Also there is the cost of assembling the railgun on the Moon as excavation will need to be done and it will need to be precision-fitted whilst on the Moon.

Food: The reason why food is the cheapest element is due to the fact that it is a part of the habitation unit. The food will be three separate fish tanks and a farm, so the cost comes from the fertilised fish eggs, the soil and the potato beds as well as the potato seeds.

Space Station: The space station costs so much due to the incredibly challenging project of having a space station 380,000km away from the earth, and the cost of assembling it that far away from any support it may need. Also there is the cost of sending the individual parts out of the earth’s orbit to the La Grange point which will require a heavy duty booster. These are not cheap.

Habitation: The reason why habitation costs so much is because of the costs of excavating and assembling the hab on the Moon. The crater will need to be excavated and then filled in which will be the primary source of the costs. Sending up the individual parts will also be expensive, although their inflatable nature will reduce costs. On the other hand, the bulkheads will be heavy and costly to send up as they are solid and very strong and dense.

Transportation to the Moon: This has a low cost as it is merely the ferrying of people to and from the space station in the Starships, which are fully reusable, and in the lunar descent vehicle. The main costs here will be the fuel consumption by both, as well as the purchase of the Starship rockets.

Transport on the Moon: The cost of transport on the Moon will be the production of the rovers, which will take up the majority of the cost, and the transporting of the rovers to the Moon, where they will be assembled on the lunar surface.

Salaries: We will pay the astronauts a competitive salary of $80,000-$140,000 depending on previous experience and whether they are currently in space or on Earth. These salaries are similar to those offered by NASA[x]. For the first six years, when all astronauts are in training, we will pay all 48 of the astronauts $80,000 as they will not be in space, creating a cost of $3.84 million per annum. After year six the astronauts in space will be paid between $80,000 and $140,000 depending on whether they are in space or on experience. When not in space, an astronaut will be paid $80,000. The maximum number of astronauts we will have in space at one time is 24 but this is likely to be lower so salary costs will be lower. We will also have to pay salaries to engineers and other staff on the ground, which will amount to $20,000,000 per annum if we have 500 staff with an average salary of $40,000.

Other costs: There will also be other upkeep costs but these will be fairly low as our technology should last a long time. We estimate that our technology will last long enough for us to make a profit. These costs will include replacing parts that break. This means that it is hard to calculate these costs as they are dependent upon whether equipment breaks.

Turning a profit

So, one of the primary objectives for the challenge was to set up an economically viable activity on the Moon, which means we will have to turn a profit eventually. Now all activities that push the frontiers of their respective fields are expensive, and this is no exception, with a grand total of $202 billion over the first eight years to set it up. Due to the massive initial cost of everything, it will take many years to turn a profit. With the first scheduled launch eight years after we start setting up, we will have $202.3 billion to make back after that, with upkeep accounted for.

Three 5 ton launches per week,

It is estimated that there are 100Kg of tritium in 5200000m^3

We mine at 0.278m/s so each 10m cycle (5m^3) takes 36s

So to mine 100Kg of tritium will take 37,000,000s or roughly 400 days

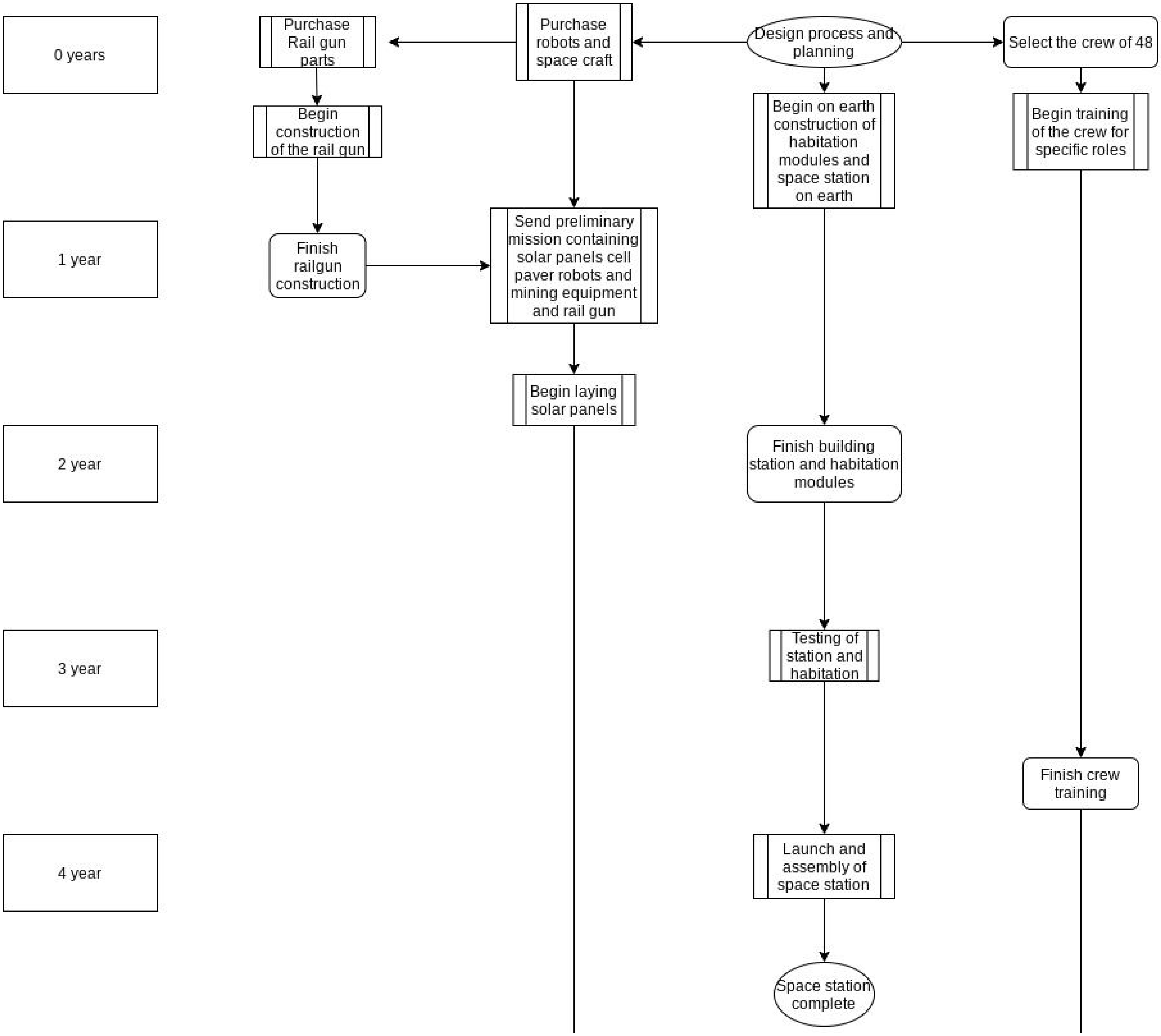
Meaning we mine 1.71 kg per week.

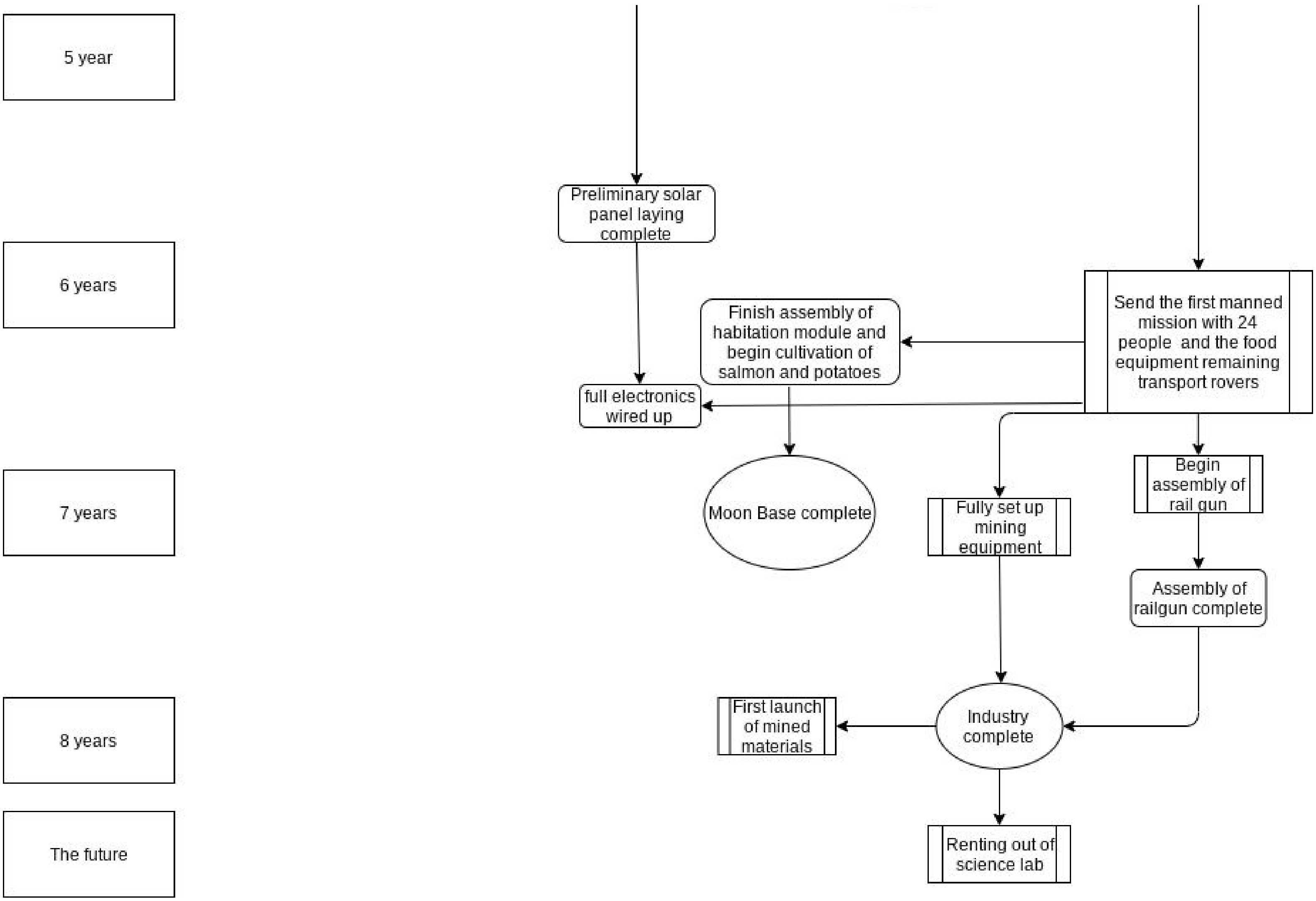
Tritium costs $30,000 per gram so 1712×30,000= $51,360,000 per week

This is $2.671 billion per year

As the initial investment was $202.3bn it will be 75.5 years before we make a profit (83.5 years after our first actions)

Some alternative forms of income such as sponsorships, advertising and research agreements may generate up to $700 million per year, but this will be mostly offset by the equipment and personnel upkeep. This is also providing that the amount of production does not increase during the 75.5 years, which it most likely will. The three lunar launches per week will be sending back research samples and the tritium as a compressed gas. One of the more sad things is the lunar regolith. Although this contains many metals, it would cause a loss if this were mined and sent back to the Earth. This is due to the high mass and low value of the metals, even with some of the more expensive ones, that is outstripped by the price of sending them to the earth. Hence the materials will be stockpiled on the Moon until there is a greater demand for these metals and they can be sold at a much higher price. To conclude, it will be economically viable to mine tritium from the Moon, despite it taking a long time to run a profit. One of the more prolific reasons why it will be difficult to sustain a profitable activity for the Moon is that space travel has not been designed for economic profitability, but with the premise of carrying astronauts to and from the earth and their intended destination as safely as possible. As a result, launch costs are very high. The very high fuel costs do not help, also raising the cost of transportation. There is also the fact that no rocket or booster was designed to be profitable, as governments and large firms were not out to make money from space.


0 years
1 year
2 year
3 year
4 year
Purchase Rail gun parts
Purchase robots and space craft
Design process and planning
Select the crew of 48
Begin construction of the rail gun
Begin on earth construction of habitation modules and space station on earth
Begin training of the crew for specific roles
Finish railgun construction
Send preliminary mission containing solar panels cell paver robots and mining equipment and rail gun
Begin laying solar panels
Finish building station and habitation modules
Testing of station and habitation
Finish crew training
Launch and assembly of space station
Space station complete


5 year
6 years
7 years
8 years
The future
Preliminary solar panel laying complete
Send the first manned mission with 24 people and the food equipment remaining transport rovers
Finish assembly of habitation module and begin cultivation of salmon and potatoes
full electronics wired up
Moon Base complete
Fully set up mining equipment
Begin assembly of rail gun
Assembly of railgun complete
First launch of mined materials
Industry complete
Renting out of science lab

Safety

Murphy's law states that 'whatever can go wrong will go wrong' and, if anything, space is the archetype of this law. In space an uncomputable number of things could potentially go wrong, whether that be mission-critical equipment such as life support or the breaking of the lunar coffee machine. This is why we have opted to go with an extra three quarters redundancy in everything we can, to try and mitigate any risk to the safety of the astronauts on the Moon. A key example of this would be the power required for our Space Station. On the ISS one of the most common causes of damage would be to the solar panels, from cosmic rays, to meteors no larger than a pea tearing through the panels. As our space station is further away from the ISS, it will receive supplies less frequently, and so will have to function without repair supplies for large periods of time. Hence we have designed it with solar panels that are larger than necessary for a space station of its size, which will allow the space station to function in the event that half of the solar panels are inoperative. This is crucial as the space station will be 'sitting dead in the water' or space in this case, hence solar panels are a mission-critical item and, if some of them fail, the astronauts must be able to continue their mission. This solution is replicated in the solar panel array we have designed for the Moon, which will have enough energy to fully charge the railgun capacitors even with up to 50% defective units.

A further example of safety is the habitation unit. The hab has two air locks in case the primary one fails and becomes unusable. The bulkhead systems in between each individual part save lives in case of depressurisation, as the bulkheads shut and each individual section is pressurised to prevent loss of pressure in the Moon Base. Furthermore, we have previously described a mechanism to keep all spacesuits on the outside of the hab. Lunar dust is very toxic and so keeping it outside the hab is imperative.

The plan is to have sufficient food to allow for considerable wastage or loss. There are three salmon tanks which are kept separate from each other in case of disease or genetic defects within the salmon gene pool so that these will not affect the astronauts' food supply. The potato samples will be kept separate for similar reasons.

One of NASA’s or any space agency’s biggest fears in space is the risk of fire. In a sealed and pressurised environment, a fire will consume all of the oxygen available to the crew, depriving them of oxygen and killing them. So, all items will be fireproofed wherever possible. The habitation unit has a countermeasure to stop a fire from killing everyone in it: each room is connected with bulkheads, allowing it to be individually sealed and pressurised with its own oxygen supply. As a result, in case of a fire, the room on fire will be sealed off from the rest of the system and cut off from the oxygen supply. Emergency oxygen masks are available if an astronaut is in the room so that they can still breathe and attempt to fight the fire. The affected unit will be isolated so that it does not affect the overall safety of all the other units.

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