Blott Mathews Challenge 2020

Luna for living (L4L)

Team Orison : Abingdon school

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OVERVIEW

As a team we loved taking on and embracing this challenge to our fullest. We have all enjoyed the challenge and loved thinking of new and original solutions to solve this problem. Every section of this challenge has been pondered and discussed by the whole team and focused on by individuals or pairs who specialize in the particular areas.

Our main focus for this plan was to maintain as much sustainability as possible especially in the transport section as that has the most potential to be damaging to the environment. Our other key ideas included making things as safe as possible and creating a solution that is entirely realistic with the next 10 years technology.

The commercial activity we aimed to find a reasonable way of making money while not expending unnecessary effort in doing so. We, as a team, feel that we have found the perfect balancing point about this which not only makes money but also has the huge potential of benefiting humans on earth as well.

The hab design we wanted to make life as easy as possible for those who stay there but at the same time try to create a self sustaining environment as much as we can. Safety was obviously a key priority and together with the transport we have tried to minimise the impact in the case of any failure.

With transport we have had the challenge of creating a sustainable reusable solution which is effective and quick. Safety was extremely important as well as a realistic solution for both cargo and people.

We chose the name Orison because it means a prayer to the heavens and we aim to give hope and inspire others just like the apollo missions did back in the 1960s and 70s while also travelling up to the heavens to achieve great things. We chose the name as a team and designed the logo to suit. We hope you enjoy our solution to the “luna for living” challenge.

TEAM

Our team is very engaged and strives to be the best we can be. Between us we have a range of knowledge that has helped enormously in this challenge. Everyone in Orison is a keen engineer and we all aspire to engineering or related degrees and jobs in the future. This has been an amazing experience for everyone and has enabled us to take part in something and think in ways we haven't been able to before.

Alex - Project Manager - As someone who loves physics and solving problems this challenge was perfect for me. I adore discovering new ways to tackle traditional problems and especially love vehicles so worked mostly on the transport section. I also really enjoyed the challenge of the habitat working through every detail and solving every problem. Organising a team has been both challenging and rewarding in itself however overall I am very proud of my team and our final result.

Freddy - As a keen potential chemical engineering or material scientist I was very interested in looking at the materials involved both in the habitation module and the transport. Furthermore I was intrigued at the possibility of designing a moon base as, the idea of humans living anywhere else but earth fascinates me, due to this inherent fascination I was heavily involved in the design of the first habitation module that requires little human construction. My a-level choices of maths and further maths as well as chemistry, physics and art set me up well to tackle this hard project, I think the project definitely stretched my capabilities and drove me further into reading about STEM related areas.

Hugo - As an A-level art scholar and physics student, both the engineering challenge and the creativity required to solve complex issues attracted me to the task of leading the designing and writing of the Helium three commercial activity process on this project. Whilst as a philosophy student, the ethics of lunar mining at first seemed problematic for me, the team was able to apply the logic practiced in the subject to help hone our process to maximum efficiency.

Will - For someone aspiring to read engineering at university, this project not only stretched my imagination, but it also cemented my idea that I wanted to further my understanding of the complex topic. I lead the team in creating a transport system that was viable to sustain a lunar base

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James - My primary job on the team was to work out a way to create a commercial activity on the moon as well as design the ROVs which are fundamental in the lunar base. I thought that this challenge helped me gasp what engineering is like on a wider scale.

Matthew - As an arkwright engineering scholar I was keen to further expand my knowledge and application of the topic, I worked alongside the team in many areas and helped to produce a final working solution for the life support systems as well as aiding in solving the main problems on the hab.

Liam - Like many of the other team members I study STEM subjects at a-level. I was very interested in creating a more sustainable lunar base so I looked primarily at the possible use of bioluminescence as well as water extraction. Furthermore I also helped the team on creating a transport design and strategy.

Ben - I plan to read Engineering at University. I was in charge of coming up with a plan for the food and nutrition aspect of this mission. I also came up with the idea for our team logo and how this could capture the essence of our team and what we stand for.

TRANSPORT

Strategy:

Our main goal for transport is to increase reusability and decrease waste while also keeping costs down but not restricting functionality. To come up with our strategy we balanced these 4 factors to get the best solution that integrates smoothly with our commercial activity as well as providing essential resources and comfort for the inhabitants on the moon.

Our transport is split into 3 main sections. Earth's Surface to Earth orbit, Earth Orbit to Lunar Orbit and Lunar Orbit to Lunar Surface. Each section has different problems to overcome, for example the atmosphere and strong gravity on earth.

In between these stages we have decided to have orbiting space stations to act as stop off points between the different stages. The Earth orbiting station is essential because the traveling from earth to earth orbit is a very different experience to traveling in space so in order to optimise the overall efficiency of the whole transport system we had to have seperate ships for these two stages. The lunar orbiting station is also very important for similar reasons as before but also as it can act as a safety net for the lunar base. If there is a failure in the base, e.g. a fire that is out of control or loss of atmosphere. The inhabitants can escape up to the lunar orbiting station and wait to be taken back to earth from there. Which is far safer than being stuck on the moon's surface.

The lunar ports also act as temporary storage for transporting food, helium and other items. Due to the fact that it will be nearly impossible to link up all the 3 stages to link at the same time.

The first stage is from the surface of earth to earth orbit. One option for this was to use a conventional rocket. These are inefficient with fuel and usually non-reusable. They are however effective at getting large masses up into orbit or beyond. Rockets are also very expensive. To reduce costs and improve reusability, the option to use reusable first stage rockets similar to SpaceX's recent tests. This reduces costs although it uses more fuel. Reusing the second stage is unfeasible as they will require so much extra shielding and fuel to survive the descent which outweighs the cost of building a new rocket. Overall rockets are too inefficient to be used as our repeatable regular ferry system, and the return of He-3 from the moon in infrequent and large quantities would saturate and decrease the market and its value. However conventional rockets will be used for the initial transport of very large masses required for infrastructure construction.

Another option is to use space elevators. This after a short amount of research was found to be completely unrealistic on earth as the forces required cannot be held by any material that we have today or will have in the next 10 years. Even if these materials could be found, the time that it would take to move even small masses from earth to earth orbit or vice versa would take weeks or even months which is far too long to be reasonable for any travel let alone travel for humans.

Another option for this stage is to use other winged aircraft and take advantage of earth's atmosphere to increase efficiency for going up and allow all parts to be completely reusable (except fuel). To reach Low earth orbit a rocket engine will be required and therefore a space shuttle type aircraft will need to be used however taking off with a space shuttle will be less than ideal so a carrier will be needed to take the shuttle up to an appropriate altitude similar to the spaceship/white knight system developed by virgin galactic. Our system will be similar however more advanced and adapted for commercial use as well as for passengers. The first stage will be a dual fuselage plane that can carry the space plane up to around 60,000ft where it can then launch on to the space station. The dual fuselage plane will then fly back down to the original base where it took off from. The space plane will ignite the rocket engine and fly up to the space station transferring any cargo then gliding back down to the same base as it took off from. There it can re-link with the dual fuselage plane ready to launch again. The cargo capacities are lower than conventional rockets, however because it can be launched regularly, I would estimate up to twice a week it is a better system and therefore the one that we have decided to go with for the first stage.

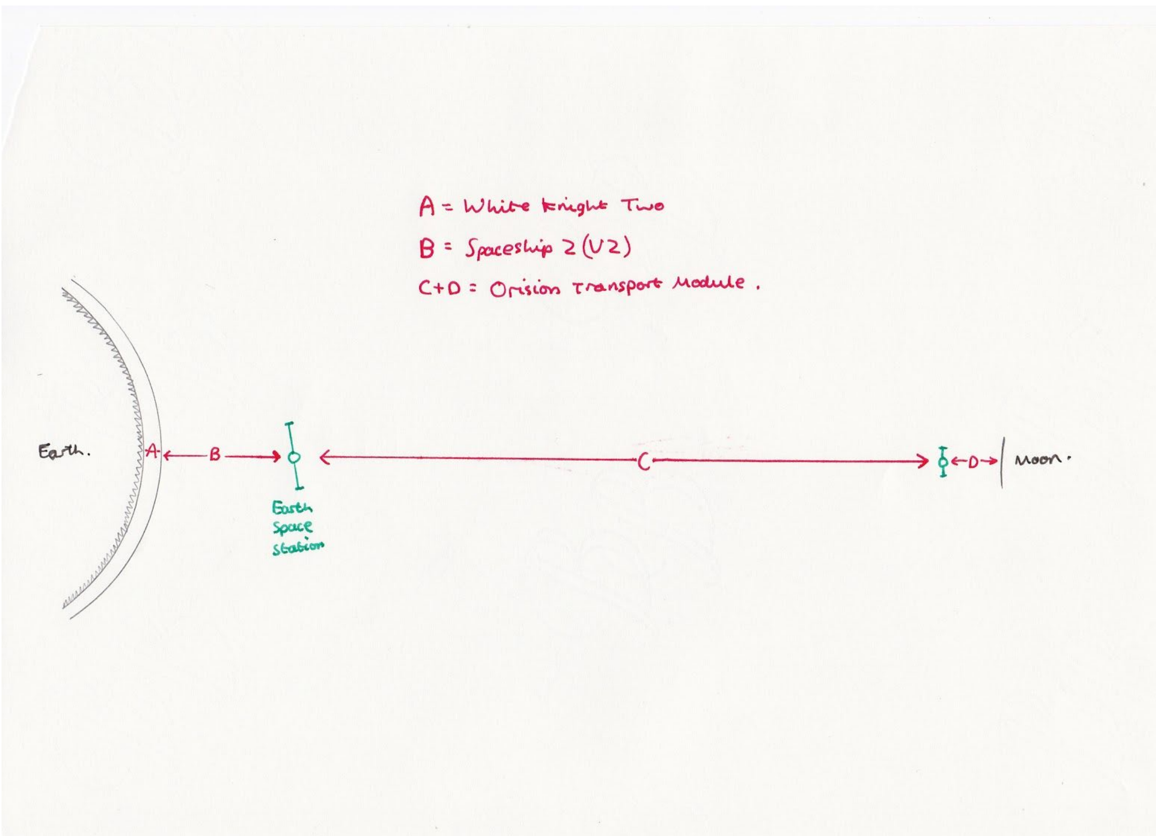
The next stage is from Low Earth Orbit to Lunar Orbit. There is much less opportunity for differing solutions here with the only realistic option being a rocket. Because it will dock with the space station it is more efficient to slingshot around the earth to get to the moon. This could take around 2-4 days depending on the power of the rockets we use. This is the same way the Apollo missions were carried out and the most logical way to go to the moon. Furthermore due to the varied cargo we will be transporting and irregular times (i.e people will only need to go up every couple of months however helium and food will need to go regularly) a modular system also makes a lot of sense. The different modules can be used to store cargo as well as transport them, this will be covered later on.

The final stage is from lunar orbit to the lunar surface. This stage cannot use wings as there is no atmosphere which limits us in the range of things we can use to launch. One solution is to use giant electromagnets to fire a spaceship or cargo into space. This solution works well for non precious cargo however may not be the best. The flaws that come with this solution and therefore the reason that we are not using it is down to the length, acceleration and energy required. In order to have a small enough acceleration to not harm the cargo/people the “railgun” would need to be many kilometers long. Furthermore the energy required to fire something even to only lunar orbit of any significant size would be enormous and far larger than what we can reasonably produce on the moon to also do the other processes that we need to do. Therefore the logical solution is a conventional rocket.

Space Elevator

Pros/Cons: The idea of a space elevator intrigued Orison, however, after further investigation we decided as a team that the idea was too far fetched. While a space elevator would hugly reduce travel cost (costing $200/kg compared to $2,700/kg on the SpaceX rocket) the technology required is estimated won't be available until at least 2050 (as predicted by China National Space Administration). To start with the main issue is the materials - carbon nanotubes (CNTs) potentially provide enough strength to make up the cable of the elevator yet the longest tube produced is less than 1m, to add to this the manufacturing of graphene is still in its early stages. Another option for the cable material would be boron nitride nanotubes (BNNTs). Similar to CNTs, BNNts could potentially provide the answer as they have the potential to hold greater loads although the longest sheet produced is 1.0mm. Finally produced in 2014, diamond nanotubes might provide the material used in the shaft. Made by staking benzene molecules under high pressure they potentially could be easier to construct yet they are untested in their tensile strength. As shown the materials are still very much in their infant stage. The proposed elevator would be at the point of geostationary orbit some 35,786km from the earth's surface showing a fault in the plan as the large scale manufacturing of carbon nanotubes could take decades. To add to this the time it takes for the elevator car to reach the counter weight in space could be months. This provides an issue for the team as a potential month delay on a shipment could be costly in both selling goods from space but also supplying the hab. Most importantly the space elevator would be humans greatest engineering feats. The chairman of the Japan Space Elevator Association put forward a low cost estimate of a trillion yen (£5 billion / $8 billion in 2008 equivalent to 8,748,412,497.25 USD) to build one. Some experts suggest a space elevator could cost up to $30 Billion just to build.

Design:

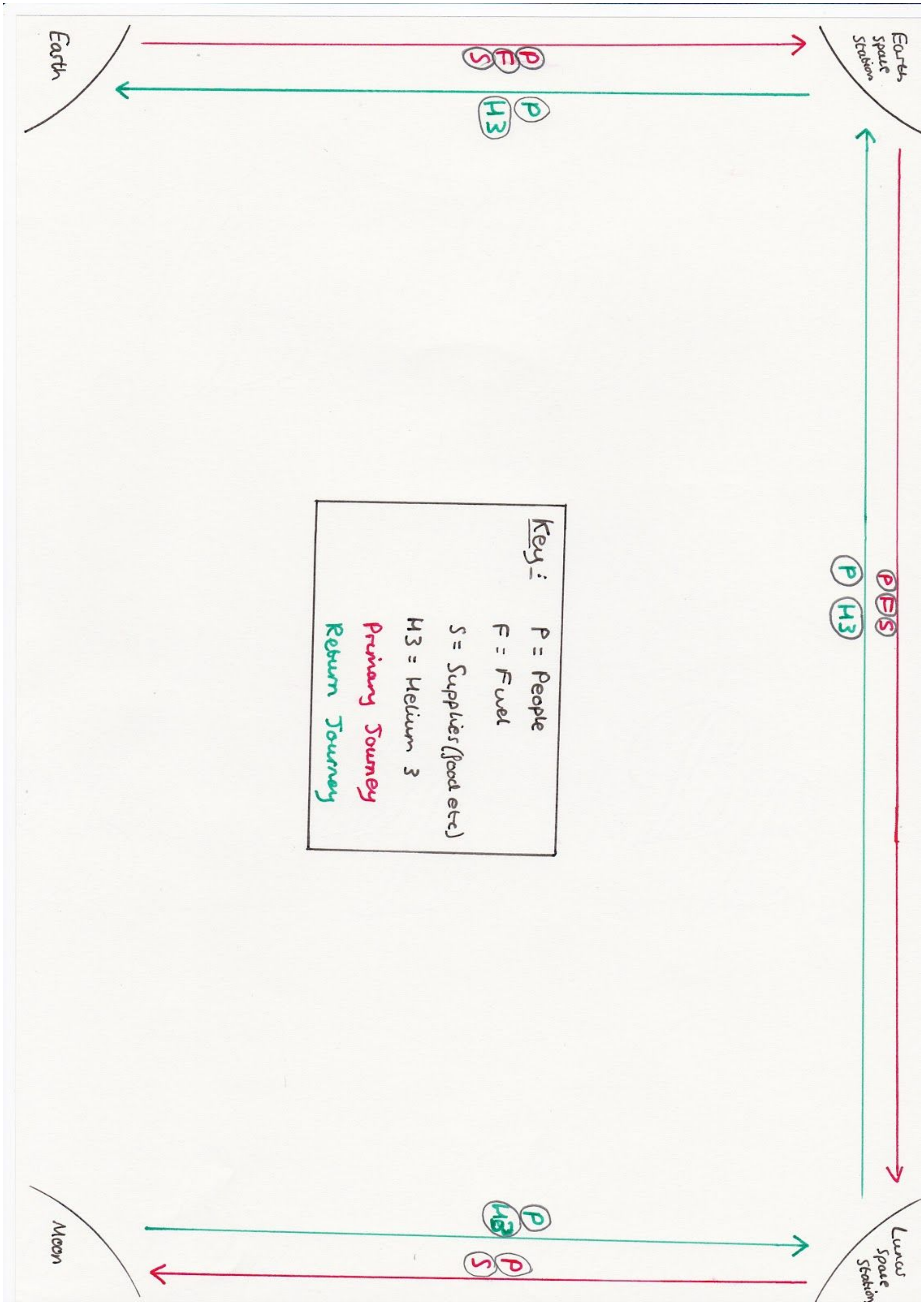


Initial transport of key infrastructure components to lunar orbit as well as the lunar surface will be done by Falcon Heavy Rockets with a maximum payload of 26,700 kg, with a reusable cost of $90 million and expendable cost of $150 million.
The Falcon Heavy will carry:

- Lunar Space Station modules to lunar orbit.
- Orison Transport Module x2 to ISS Extension, 2x to LSS once construction is complete.
- Construction equipment and base materials/infrastructure to the lunar surface.

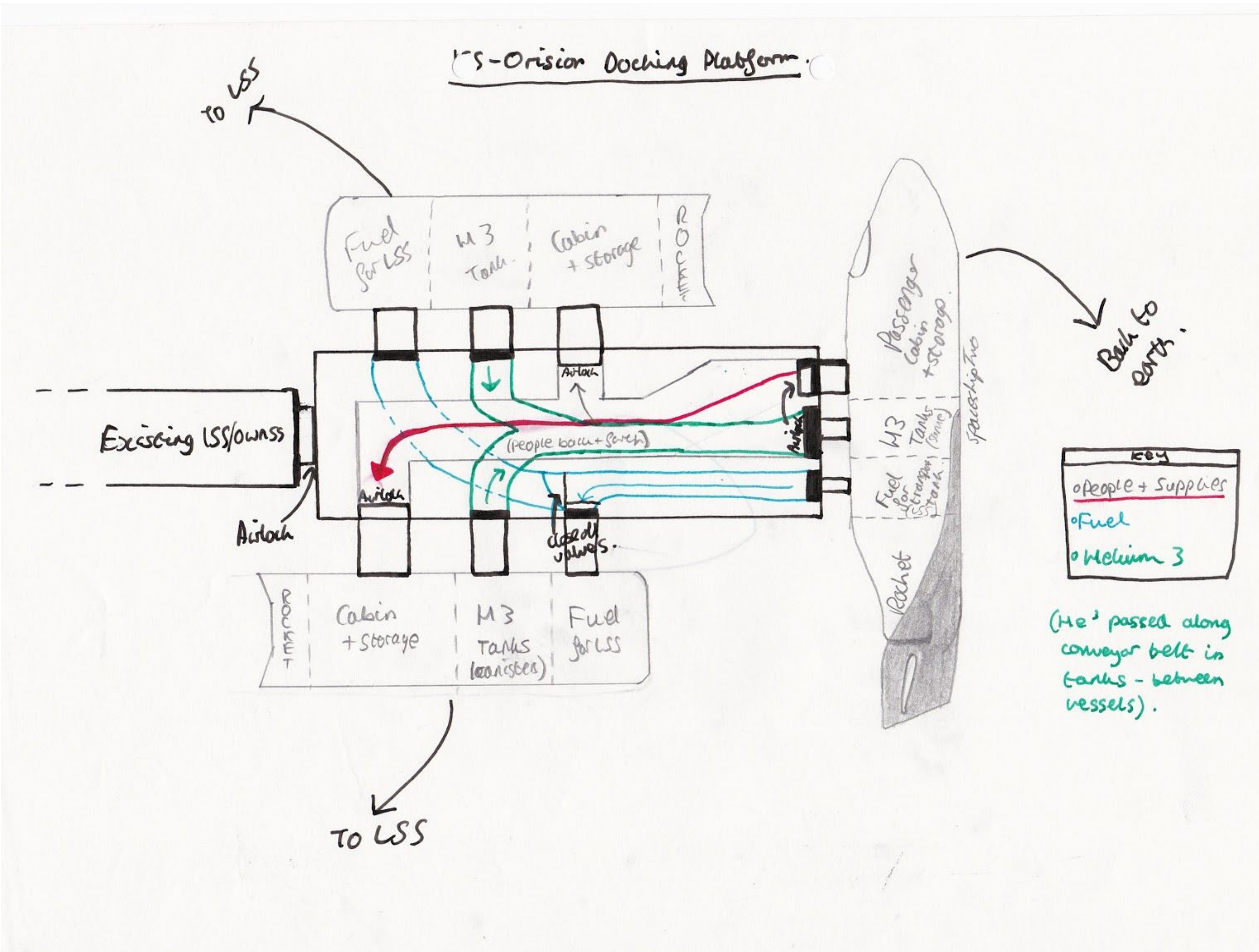
- Launch 1: Initial HAB central operating centre and life support systems
- Launch 2:Energy generation apparatus, Lunar Rovers
- Launch 3:Mining infrastructure & FFC Cambridge Infrastructure.

During normal operation and when construction is completed, supply and transport will operate according to this model:


Earth
Earth Space Station
Moon
Lunar Space Station
P F S
P H3
Key:
P = People
F = Fuel
S = Supplies (food etc.)
H3 = Helium 3
Primary Journey
Return Journey

Explanatory Timeline:
Astronauts, fuel for transport pods and general lunar supplies depart from earth's surface aboard the Virgin Galactic Spaceship Two V2. The spacecraft it strung under the central wing of the double fuselage White Knight Two aircraft, which, when it reaches its service ceiling of 70,000 ft, releases the SS2 V2 spacecraft.
Upon its release, the spacecraft ignites a Polyamide plastic fuelled rocket which then propels it to LEO.

The SS2 V2 then slingshots into LEO, where it reaches the ISS and subsequently commences docking with the Orison platform potentially with the assistance of an automated robotic arm.

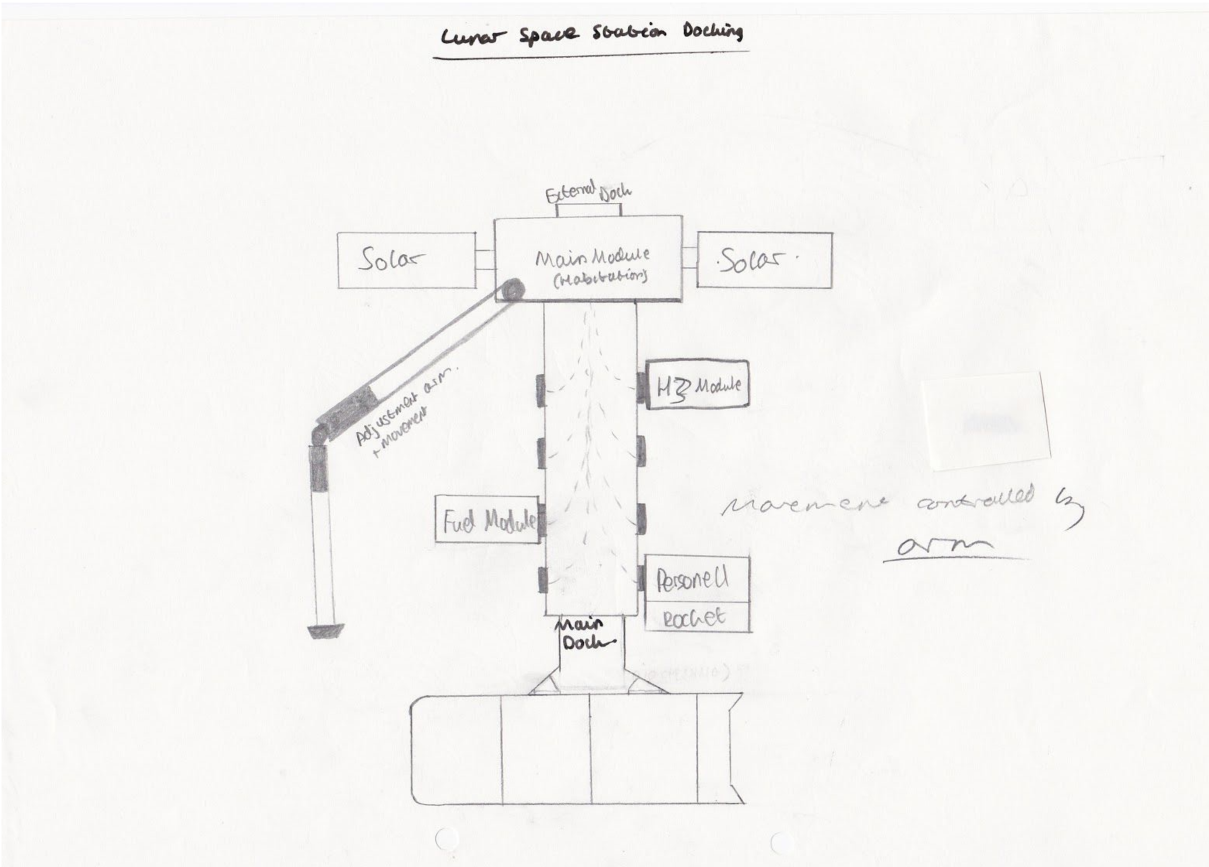


Once hard docking has been completed, movement of supplies can commence. The liquid rocket fuel is moved by temperature controlled pumps (similar to those in a conventional rocket fuelling system) and pipework into an awaiting Orison Transport Module containing an identical storage tank. Movement of people and supplies done by hand making use of the interconnected space illustrated in the diagram. The awaiting Orison transport module will have come from the moon, hence it would be fully loaded with active Helium 3 canisters. These canisters are rotated around a drum and one by one are moved along a simple rail track like assembly into the identical storage system on board the SS2 V2 Spacecraft. Movement of people can occur in either direction.

Once all He3, rocket fuel, personnel and supplies have been appropriately moved between docked spacecraft, the SS2 V2 will break away from the ISS, re enter the earth's atmosphere and perform a conventional runway landing at the Orison Base. Here, it can be refuelled, checked over and reunited with the White Knight Two aircraft, ready to be deployed again.

Meanwhile the OTM will detach from the docking module and wait to reach a safe distance before firing a small and ultra efficient liquid fuel rocket, which will propel the spacecraft on a precise and guided trajectory towards the Lunar Space Station. The journey will take approximately 2-3 days.

The OTM will then arrive at the Lunar space station, where it will attach to the main LSS robotic control arm, which guides it towards the attachment module. When it berths to the attachment module, the He3 canister module (empty) and the Liquid fuel module (full) separate from the OTM main body, smaller robotic arms attached to individual ports take over and guide the two now individual moduled toward the correct sections. Here they dock to appropriate points on the docking platform via specialised ports.



Still attached to the main control arm, the main rocket and personnel module of the OTM are now free to dock to one of the main ports of the platform. Here personnel and supplies are able to move to another OTM main body, which can then attach to the empty He3 Module and then journey down to the moon. Alternatively, if there is sufficient fuel, upon approach to the LSS, only the fuel module (full) could be jettisoned and attach to the docking platform, and the remaining He3 and personnel modules could simply continue down to the lunar surface without any changes.

The fuel module remains on the LSS to supply the station with fuel, that can be stored on board, or immediately be used to refuel an OTM main module rocket. This would be facilitated by temperature controlled pumps and pipework similar to the ISS system, and similar to the ones used in conventional rockets to send liquid fuel to combustion chambers.

When the OTM module (minus the fuel section) arrives on the lunar surface, it performs a controlled descent touchtown at the designated landing pads. Here supplies are unloaded, as well as empty He3 tanks. Empty tanks can then be replenished by lunar mining operations and then reloaded onto the lander. Alternatively, the modules could remain on the lunar surface until enough He3 has been procured. The replenished lander can then launch back up to the LSS with remaining fuel.

Lander modules can then re-dock with the LSS, passengers and cargo can be moved to a different main OTM module or the occupied main module could be refuelled. The main OTM module and replenished He3 module can then dock to the now empty fuel module with the guidance of the main arm, and then the completed OTM module can journey back to the ISS and the process can be repeated.

Component Analysis of Supply Chain:

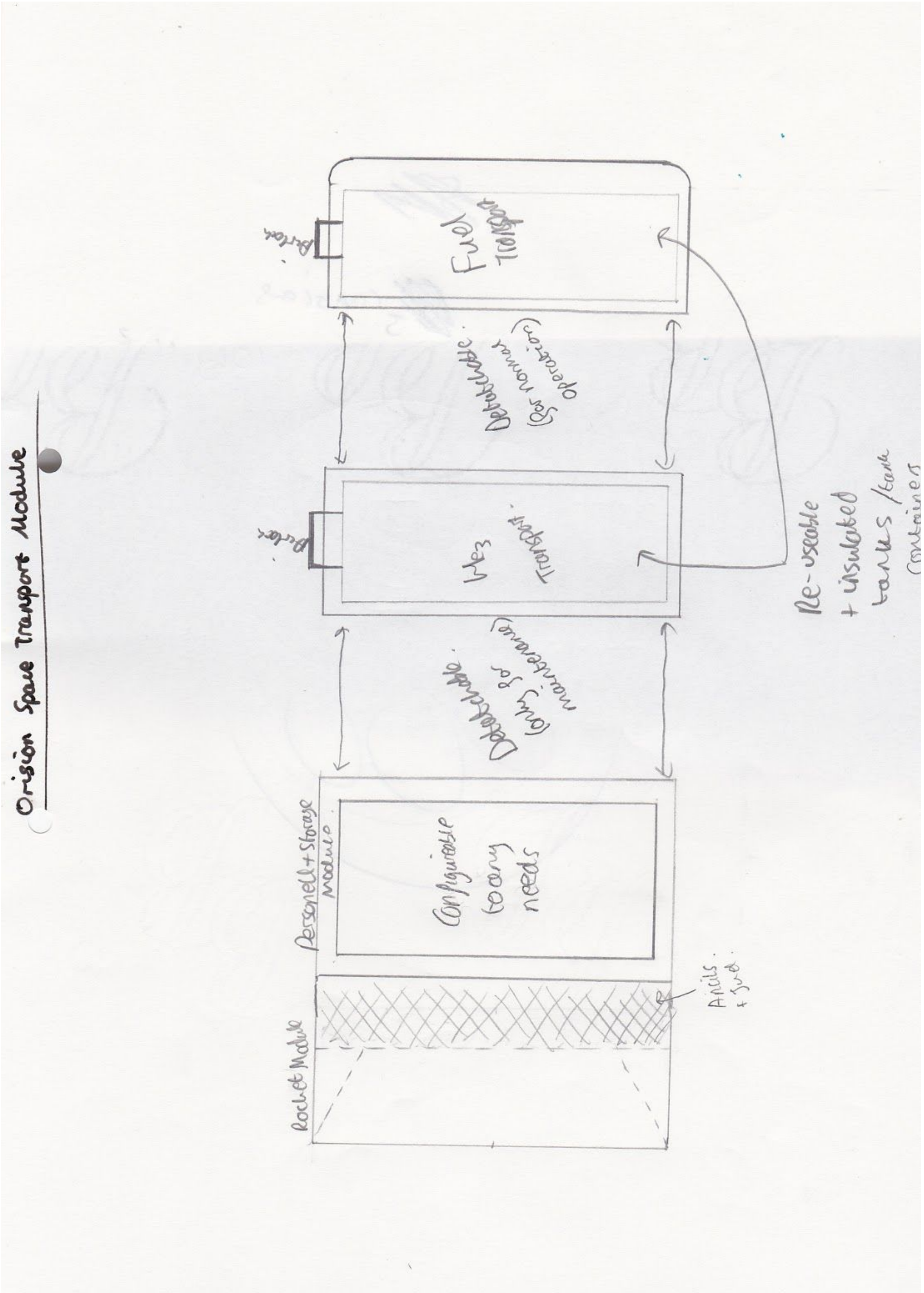
Ascension Islands Hub: Will act as the base of operations with all command and control powers. The hub will also stock vast reserves of spare parts, provisions, supplies and liquid rocket fuel for use in space. The base will also house the main runway and hangars for the operation and storage of the earth based transportation system.

ISS Docking Extension: Used as a simple docking portal, OTM spacecraft attached by standard arm-controlled docking system, however the SS2 Spacecraft docks by retracting top surface fairings to reveal 3x docking ports that attach to the portal in the same way. At any one time, the ISS Extension is able to house 2 OTM transport modules and one SS2 V2 spacecraft. Docking happens in only one orientation, due to the fact that each port is specialised to facilitate the movement of either fuel, He3 canisters or personnel and supplies.

Lunar Space Station: Similar system to the ISS extension in terms of the docking portal, however 2x ports are connected directly to the on board fuel storage, 2x are blank and simply function as anchors for He3 Modules, and 4x are fully open to allow docking of main human module. The station incorporates large capacity rocket fuel tanks to act as storage to refuel OTM main modules, reserve oxygen tanks for use in an emergency, a crew habitation and storage module that can act as a place of refuge should any form of accident occur on the lunar surface.

Lunar Base (transport infrastructure): Will incorporate temperature controlled liquid fuel reserves for emergency use, and a double launch pad area a safe distance from the main base (the base and launch pads will be connected by a high speed carriage) Helium 3 canisters could be transported either by a conveyor system or by lunar rover.

Orison Transport Module (OTM): Diameter approx 11m, Constructed of 3 independent modules, with the main module incorporating a single, highly efficient rocket motor (modified Draco thrusters) (feasible within the decade) running off NTO/MMH mixture (this was chosen due to the good ratio of efficiency compared to propellant used and for its storeability). Also incorporated into the main module is a crew transport capsule incorporating supply storage. In addition to this there is a single compact fuel cell on board to provide power to the various systems and failsafes on board. The second module incorporates the He3 canister carousel, this is a temperature and pressure controlled environment with optimum shock absorption characteristics to protect valuable helium 3 in the event of a collision. All stored canisters are completely interchangeable across the entire transport network. The third module (nose) incorporates the dual temperature and pressure controlled tanks to house liquid oxygen and liquid hydrogen (feasible within the decade). Could also be able to be adapted for the transport of alternative fuels eg Liquid O2/H2. The tanks converge to two separate points that feed into specialised airlock ports, that when they dock, they form two separate seals between them to pump both fuels. Pumps will always be housed in the space station platforms for ease of maintenance/replacement.

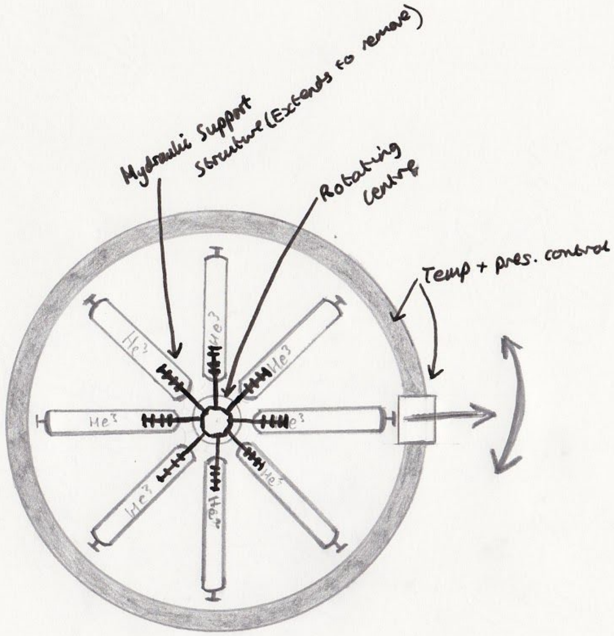

Orision Space Transport Module
Rocket Module
Personell + Storage Module
Configurable to any needs
Detatchable
(only for maintenance)
He3 Transport
Detatchable
(for normal operation)
Fuel Transport
Re-useable
+ insulated
tanks / tank
container

SpaceShipTwo Variant:
Will be an adaptation of the existing spacecraft adapted on contract with Virgin Galactic. The adapted spacecraft will feature uprated life support and power generation systems, two separate temperature controlled chambers for both the fuel and He3 canisters, an enlarged fuselage to accommodate larger loads, an uprated rocket motor to allow it to reach LEO. There will also be a retractable fairing on the top of the fuselage that when retracted, reveals 3x specialised docking ports, complementary to those on the ISS extension. The SS2 will have two permanent pilots to facilitate docking etc, docking guidance will be facilitated by small externally mounted CO2 boosters.

Additional Technical Specifics:
Docking of OTM and SS2 spacecraft will be completed using 1x standard 'common berthing mechanism' and 2x internally specialised 'common berthing mechanism'. It would also be possible to use the 'international berthing and docking mechanism', the former being Non-androgonous (gendered), and the latter being androgynous (non-gendered).

Docking will also follow the standard soft/hard docking state process. The initial soft dock makes contact and latches connectors, and the following hard dock activated airlock seals and the doors can be opened.

OTM He3 Module:



Basic He³ Canister Module Profile

HABITATION

Initial hab overview:

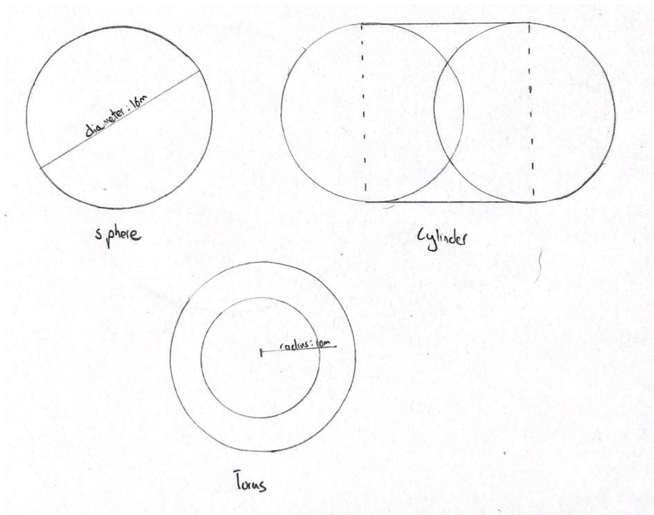
Due to the lack of atmosphere on the moon the initial HAB must be able to withstand the intense radiation (in the form of cosmic rays and solar flares). The initial HAB must be easy to construct with minimal human input and be a good foundation for further expansion. Orison has therefore decided on the initial hab being formed from an inflatable shell with lunar regolith as radiation shielding as well as providing some form of defense from the extreme temperatures and possible space debris hitting the moon surface. Furthermore an inflatable HAB is light thus reducing costs of transportation and ease of packing due to the fact that it can be folded in transportation. Thus providing us with a large operational volume but a small transportation volume. This is particularly useful as space travel is greatly confined to the volume of the launch vehicle and its capacity.

Stage 1 of initial HAB:

In the first phase the lunar lander will detach from the lunar lander. The lander will split after landing, leaving the main cylinder to fall on the lunar surface under the influence of gravity. On impacting the surface the cylinder containing the hab will begin to inflate using air from earth stored in pressurized containers. This then provides the shell for the initial base and a strong foundation on which to build on. The inflated shell will be composed of an internal air bladder covered by a strong multi-py fibre known as Kevalar-29 made by the DuPont chemical factory who claim that is has a strength of 525 N/cm therefore we can assume that the shell of the HAB can be around 5mm totalling of 44 layers of the fibre each with an individual width of 0.114mm.

Volume and design:

In creating an initial HAB we need an appropriate volume this is determined by many factors such as the number of crew members as well as the jobs that they will be doing. Furthermore we need to strike a balance between how much we can make the crew members endure without being too cramped and inconvenient. Therefore a simple open volume is key in creating the HAB as it allows for the crew to re-organize and a tailor the inside of the HAB for their own needs. Therefore as a team we suggest that we use a simple sphere with a diameter of 16m thus a total volume of 2144.66m^3 . The shape of the inflatable is hugely variable however we decided that a simple sphere was best as it didn't require any sort of hoops or other structural elements. We decided against using a more complex shape such as a cylinder of a torus.



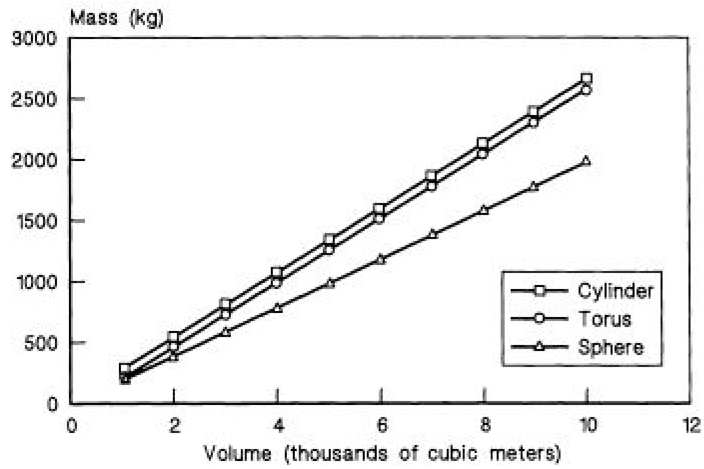
The pneumatic stress (σ)on the shapes can be expressed as:

Sphere: σ =Pr/2

Cylinder: σ =Pr/2 for circular end. And σ =Pr for the rectangular centre.

Torus σ =Pr/2 x ((2+rSin θ /r)/1+rSin θ /r))

The sphere is also the most efficient in terms of the volume it holds and the mass of itself (see graph). As well as the stress is evenly distributed throughout the inside surface of the HAB. However a major drawback of the sphere design is that the walls are cured from very angle whereas in a cylinder design the walls in the middle section are curved in one direction. The torus is effectively a cylinder folded into itself which means that there is no end cap thus reducing the mass of it, however the large open middle serves no purpose and takes up valuable space on the surface.



Creating a safe environment:

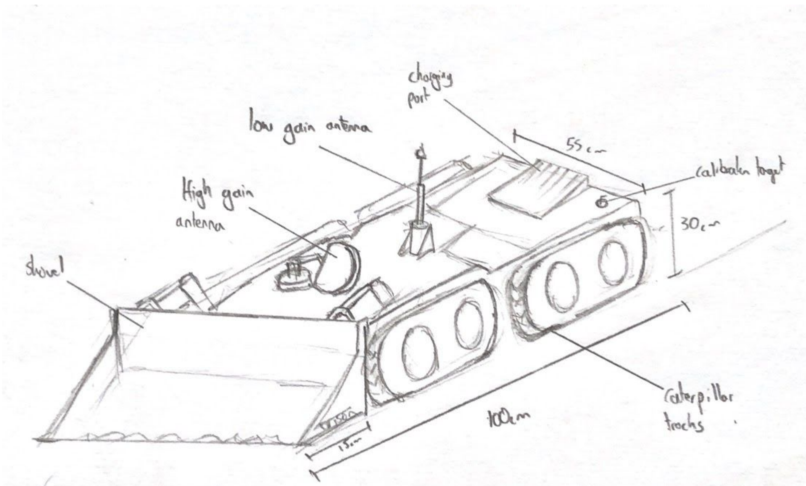
The sphere when inflated will have a diameter of 16m with an internal pressure of 101.4kPa (standard sea level atmospheric pressure on earth). This pressure was chosen due to the fact that it is slightly higher than what it is for most people on earth but it provides some internal force which will help keep the base rigid and can support the radiation shielding that we will address in the future. We plan to use a Environmental Control and Life Support System (ECLSS) system which is used on the ISS to maintain the atmosphere nitrogen and oxygen levels (in addition to maintaining water quality). The pressure created in the hab by the ECLSS is enough to conserve life and protect it from the vacuum that is space as well as support the structure which is total has a mass of 2200kg. As well as regulating pressure it is also necessary to regulate the temperature of the HAB. It must be able to cope with the the temperature swings of the moon which can be as low as 100K and as high as 400K. The poor insulating nature of the Kevlar will be combated by having a reflective inner sheet to preserve the temperature inside. The low thermal conductivity means that the temperature of the HAB may fluctuate between 291K and 294K. While the HAB may be at room temperature on the lunar surface it may be subject to extreme temperatures during the transportation phase. Therefore to reduce this risk the cylinder that the deflated shell is in will be a thermal insulator to keep the inside a more constant temperature and ensure that it doesn't burn at any point.

Environmental design issues:

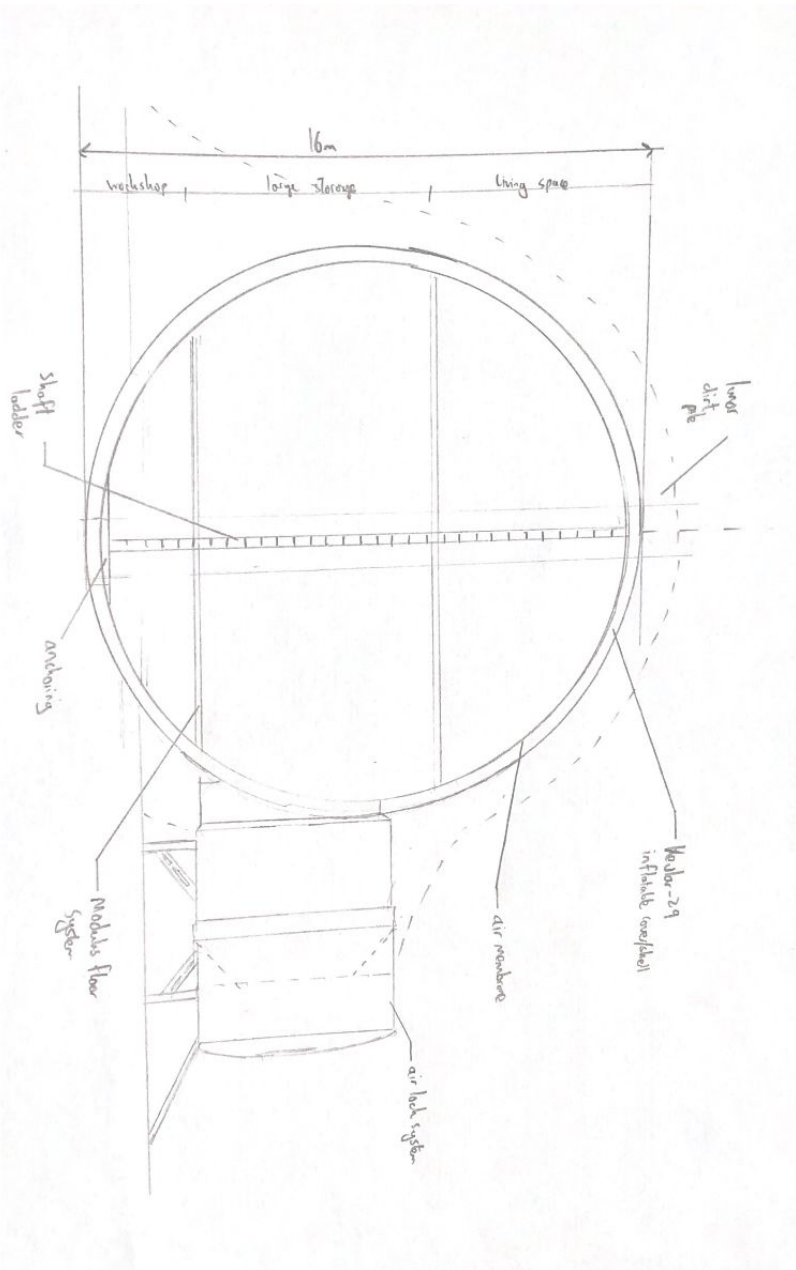
Unlike Earth the moon doesn't have a thick atmosphere or strong magnetic fields to protect it from radiation, so when designing the HAB we had to take this into account. To account for the high levels of radiation that the moon receives Orison has decided to make use of the lunar soil which can provide valuable radiation shielding. To add to this the lunar soil helps regulate the temperature of the hab. The pressure inside the HAB of 101.4kPa is capable of supporting a thickness of 40mm of lunar regolith assuming a uniform density of 1.6g per cubic centimetre. Obviously this would require some reinforcement as although the pressure is enough to keep it rigid, in case of a leak the HAB crumpling under the mass of the lunar dirt would be a disaster. Something to account for would be the abrasion of the HAB shell by the lunar soil as minor vibrations could cause the dirt to gradually wear through the material. To this end a thin layer of resistant proof material could be added or as we suggest a coating could be applied to the outermost layer of fibre. We suggest a thin layer of a ceramic coating to prevent this.

Appling the shielding:

While the shielding could be applied manually we suggest the use of two small drones to effectively shovel the lunar dirt onto the hab shell. The drones will be automatic and will require little human effort. The basic idea for the drones is based on an automatic lawn mower - while this may seem trivial the basic idea of an automated machine that uses GPS is the foundation for which we are designing our drones off. The drones will be powered by a solid state battery. As a team we ruled out the use of a conventional lithium ion battery as the main issue is that lithium ion batteries use a flammable liquid electrolyte to move the ions between the sides of the battery. This provides an issue as the battery might not be able to survive the harsh temperatures of the moon as the liquid might freeze thus potentially jeopardising the setup of the HAB. Therefore we suggest that we use a newly developed solid state battery that relies on a ceramic electrolyte. Instead of having liquid surrounding everything, the different parts are stacked into solid layers, which also makes the battery more compact. The battery will deliver a total voltage of 30V and should give the drones a run time of 3 hours. The two drones will work at different times to ensure an even coating of lunar dirt (the drones will work 3 earth hours then charge for 2 hours). The charging ports will be powered by one of the small nuclear generators that is placed down with the initial hab. The small size of the generator means it can be unloaded with the HAB requiring no human effort. To move the dirt the drones will have an attached shovel which will be composed of stainless steel and aluminium (similar to the trenching tool that was used in apollo 14 to collect samples). The drones, over a period of 1 month, will cover the hab in around $16m^3$ assuming a uniform thickness of 40mm. This totals to $0.53m^3$ each day which is equivalent to just over 6 full shovels per earth day (shovel dimensions width: 0.55m depth: 0.15m). Due to the treacherous nature of the lunar soil the drones will have caterpillar tracks to ensure solid traction thus allowing them to gather a large amount of regolith without getting stuck. An onboard GPS system creates a map of the area around the hab, including where any potential hazards are as well as the position of the hub and charging port. Overall dimensions including shovel (LxWxH): 100x55x30 cm



Summary: The first habitation module will serve as the starting point for further lunar expansion. It will provide a storage area as well as a small workshop and crew living areas. The storage will be on the first floor of the hab for ease of transporting goods in and out of the hab. The floors will be composed of light weight modular flooring that will be put in when the crew arrives, as well as modular beds. Finally the crew will secure an anchor, ensuring that the hab stays in place. The initial cylinder holding the inflatable shell will act as an air lock, this way no external large parts are needed to be fitted to the hab as the inflatable shell inflates from the airlock. This provides a strong and reliable structure for Orisons lunar living plan in which over time we can expand from.



Here is a brief design of the first hab that will be constructed, in this diagram you can see it is partly under the lunar surface which will help keep the habitation module in place as well as help regulate the internal temperatures of the base itself.

Permanent hab:
The second stage of construction of the habitation module will require the use of the forged aluminium acquired from the lunar regolith. In short, the plan of expansion will involve building livable areas underneath the lunar soil, facilitated by the digging capabilities of the ROVs.

The hab design is entirely underground with multiple entrances. The entrances will all be arilocks with a two stage fail safe system. I.e. any leaking and both sides of the airlock will instantly shut. They will also be lifting platforms to allow goods and other stuff to be taken to and from the lunar surface if necessary. The main entrance to the base via the train will be completely air tight to avoid the people moving to and from the train having to get suited up. The train will essentially arrive into a giant airlock tube which is directly linked to the base. Throughout the base thick aluminium doors will be able to be closed in order to protect certain parts of the base if necessary.

Materials:
The construction will be undertaken using aluminium plates, dimensions: 2 metres by 1 metre by 5 centimetres. This is a comparable thickness to the aluminium walls used on the ISS.(Commonly cited as ¼ inch) The mass of one aluminium plate will be 271 kg. (assuming that the density of aluminium is 2710 kg/m^3) Due to the power requirements of the mission, only 5 tonnes of aluminium may be forged per 24-hour cycle. Of course, if a greater fraction of the outpost's power can be used in refining aluminium, then the mass of aluminium being forged daily can increase. The limit imposed by these power requirements, therefore, is 18 plates per 24-hour cycle. This means that a total surface area of 36 m^2 can be produced daily. Other sections that are more complex, such as airlocks, must be shipped from Earth, as the ability to manufacture complicated machinery on the Moon is limited.

Construction:
The aluminium plates will be joined together using electron-beam welding. This entails welding the plates together by firing a stream of electrons from an electron gun at the aluminium to heat it. Electron beam welding is a technique that works better in vacuum than in atmosphere, due to the fact that the beam is not dissipated. Unfortunately, electron beam welding requires a large amount of energy, and produces a large amount of heat. The estimated energy requirement of electron-beam welding is 100 kW. As the estimated time taken to weld a metre-long join of aluminium is assumed to be 20 minutes, (low estimate due to unfamiliar working environment, balanced by more training and experience) 34 kWh(rounded up to allow for mistakes) will be required per metre welded. That amounts to 272 kWh per metre of tunnel, not accounting for the ends.

Design:
The ROVs will be used to dig 2-metre wide and 3-metre deep trenches in the lunar regolith. The tunnels and rooms will be constructed in the trenches as per normal for construction in an open space, and then be buried in regolith by the ROVs. The construction of the main underground complex is not expected to be instant, but will be a process occurring over the period of colonisation.

Human Amenities:
In order to function humans need basic resources to be able to work efficiently. These range from sleep and relaxation to excreting.

Firstly sleep, The astronauts will be sleeping in separate bunks in rooms with a small area for personal belongings. These bunks will be 4 to a room with 5 or 6 rooms to accommodate everyone as the exact numbers will not always remain constant. As time goes on and the base potentially expands to fit more people more rooms could be added. In order to get appropriate amounts of sleep humans need day night cycles which can be replicated by the lighting in the base.

Furthermore excreting is an essential process of life. Toilets will be provided around the accommodation areas and linked to the water reclamation and life support systems. The excrement will have the water removed which will then be UV light sterilised and then used elsewhere. The dried waste can be used as fertiliser for the plants to grow and develop but will also be sterilised before hand.

Recreational time is also important for sustaining a longer term life. On the base will be some points for relaxation for example chess or similar. The base will have constant access to earth's internet so laptops and other devices could download data for other entertainment such as netflix or spotify so that the commander in charge can download all their disco songs.

Communications

Communications are essential for everything. On the moon communications will be done via microwaves and radio waves. Communication to and from the moon is equally important and can be done via radio and microwaves also. There is a lag time between the communications between the moon and earth however it is only between 2.4 and 2.7 seconds.

Safety:

Safety is a key part of our base design and loss of life will be avoided at all costs. The different parts of the base have particular safety requirements.

The fundamental design of the base will try to avoid as many issues as possible by having an extremely strong structure, lots of bulkhead style doors, and personal safety equipment around the whole base.

Firstly fire is a very possible and dangerous thing. If a small fire broke out in a lab or the workshop for example, foam fire extinguishers could be used to quench the fire. CO2 is not appropriate as it can overload or damage the life support systems and can cause passing out if it displaces the oxygen. Water can’t be used as it is a limited resource and could damage some of the equipment in the base far more than foam could. In the event of a large fire, the airtight door could be closed to seal off the area and contain the fire. Then the ventilation would be shut off before the fire would be extinguished by foam. If the fire is uncontrollable or the base is damaged so that it cannot be inhabited in it will be evacuated which will be covered later.

Secondly Loss of atmosphere is a major problem. The base will be built to exacting standards so this should be extremely unlikely however the possibility is still there. This can be mostly

contained by the air tight doors which can seal off the different sections where a leak may occur. Evacuation will take place if the base is uninhabitable however space suits will be available in a range of locations around the base so that a leak could be fixed in these circumstances. The ventilation system will also be able to be shut off too.
Sensors in the different sections of the hab will be able to sense fires, pressure and unusual gases from a safety perspective as well as temperature, humidity so that the climate control system can adjust the conditions.

In the event of a lack of food or water either due to a separate problem or crop failure there will be freeze dried emergency food for at least 2 months in order to support 20 people. This time scale has been chosen because that is the maximum time that it could take to get people off the moon in the event that all the transport systems break or allows enough time for more food to be brought or crops to be recovered.
If just the train breaks then rovers will be able to act as a temporary solution.

In the event of a major or large scale problem evacuation procedures must be taken. The evacuation will include getting everyone out of the base and into the train which can take them to the ascent vehicle to leave for the moon. A simple evacuation will have everyone getting on to the train then leave however if the problem is with the train then space suits will be available in order to use rovers to get to the ascent vehicle.

In the very unlikely case that the base, train, and ascent vehicle are not usable then the inhabitants will be able to use the space suits using the spare oxygen tanks, water and food from the base to via the suits to stay alive on the lunar surface until they can be evacuated.

Gym:
In order for the astronauts to stay healthy for the duration of their stay, and due to the low gravity they will need to do regular exercise in order to keep their muscles and bone structure sufficiently strong. To this end we are planning on putting a very small workout space for them. This will consist of an energy free curved running machine and a weight bar. We have chosen that type of running machine over a regular running machine as it is just a track on two bearings and so doesn't contain any motorised electronics that could be a fire hazard. However due to the lower gravity on the moon body weight and the weight of the bar will be greatly reduced and so exercise would have a lesser effect, to counter this we will be taking exercise bands of different elasticity up to the moon with us. These will hook between the running

machine and a harness to give the effect of greater gravity, and attach between hooks on the floor and the weight bar.

Workshop:

The workshop is mainly going to be used by the astronauts to do repair work to the rovers and the base. Therefore they will need in the workshop all of the tools to fix any problems that could occur. The possible problems that could occur with the rovers that are fixable on the moon would be damage to a singular module of it that would be replaceable, or damage to the wiring by any debris kicked up. For this reason they will be given impact wrenches with the required bit sets. They would also be equipped with angle grinders to cut away and warped metal. We will be using lithium ion Makita tools as the workshop will be under atmospheric pressure using air, and so would not need specialist tools. The workshop would also be equipped with the basics such as a soldering iron for any electronics, and lubricants for the rovers. Given that there would need to be emergency fixing supplies for the base in case an unforeseen disaster happens we would equip them with Tungsten Inert Gas welders to add an aluminium 'bandage' to any cracks or splits in the wall of the base. In order to check the base's structural integrity without damaging it we could use Non Destructive Testing, specifically X-Ray photography to identify these weaknesses that might need repair works in the wall or in the welds.

The workshop will have a much larger airlock that leads directly to the lunar surface to enable rovers and other vehicles to be taken down into the workshop or larger equipment for repair to be taken out to the lunar surface. Orison will have specialist rovers of a similar base design to the other rovers for the inhabitants to use for getting round the lunar surface. These will mainly be used for doing repairs so will be able to operate out of the workshop and carry any required equipment.

Hospital:

A fully fledged hospital would not be required on the moon however being able to prevent possible life threatening injuries or simple injuries is essential. The majority of the medical bay will be used for basic first aid however some more complex equipment will be necessary for example a oxygen mask/supplier.

The people selected to go to the moon, like current systems, would be hand selected and very healthy so things such as appendicitis would have greatly reduced chance of occuring or eliminated.

Power production for base:

Nuclear Fission:
While nuclear energy is still slightly controversial on earth it has huge capabilities for sustaining a population on the moon as it provides a constant flow of energy unlike a solar based energy supply. A fission reactor (viable technology since the 1950s) works by splitting atoms and releasing energy in the form of heat, which is converted into electricity (see equation below). Specifically, Orison proposes the use of radioisotope thermoelectric generators. Radioisotope thermoelectric generators have no moving parts and have been used in satellites, space probes, and uncrewed remote facilities such as a series of lighthouses built by the former Soviet Union inside the Arctic Circle (showing their reliability). The radioisotope thermoelectric generators (RTG) can operate with a variety of nuclear fuel sources: $^{238}\mathbf{Pu}$, $^{90}\mathbf{Sr}$, $^{210}\mathbf{Po}$ and $^{241}\mathbf{Am}$. Orison has decided on using plutonium-238 due to the fact that it requires the lowest radiation shielding (2.5mm of lead on earth) and also due to its moderate power density 2nd out of the listed elements of 0.54 W/g with a half life of 87.7 years. To add to this the rough lifespan of an RTG with a plutonium fuel is around 23 years which is sufficient for the lunar base as the transport cost of a reactor is relatively low as they are reasonably small. They output a total energy of 40kW which is roughly enough for 8 houses however we propose the use of 4 reactors to supply enough energy for the base. This includes charging rovers as well as any tools. The reactor would use a silicon–germanium alloy as a thermoelectric generator to convert heat from the radioactive material into electricity which is only around 10% efficient, thus paving the way for a more efficient model in due time- which would be adapted in the future as the simplistic design can be upgraded at any point.

Phase II of Nuclear Power Production:
When the base has been operating for a sustained amount of time (e.g. 5-10 years) Orison suggests the use of stirling radioisotope generators which are more efficient but haven't been fully tested on earth or in space. The main reason for the use of these generators later on is due to the fact that they haven't been fully tested and require more space - for that reason we will

adapt these when the base has more infrastructure that can sustain the larger reactors. They are more complicated as they use a piston which is driven by heated Helium gas. This model provides a better transfer of thermal energy to electrical energy of around 25%. The main system is very similar to the radioisotope thermoelectric generators so it might be possible to convert them at a later date into sterling generators. Once again the nuclear reactor would only supply the base as we believe that a constant flow of energy is necessary to support life. The combination of 8 stirling reactors would produce an output of roughly 100kW.

Orison mining operation energy supply:

To provide the vast amount of energy needed to sustain the mining operation Orison has once again decided to use nuclear fission reactors, however to sustain the large operation we have decided to use nuclear fission reactors similar to the ones on nuclear submarines. The French Rubis-class submarines have a 48 MW reactor that needs no refueling for 30 years making it ideal for the situation on the moon. The reactors are tried and tested as since 1975 the US have been using them in submarines. The reactor that we will be using will use enriched Uranium, the highly fissile source is paired with a burnable neutron poison which slows the rate of nuclear fission such that the reactors have a high power density (created by the fissile source) but a long life. At the moment all the reactors have made use of pressurized water to create steam thus driving a turbine, however the lack of atmosphere on the moon makes it necessary to make use of a helium driven turbine similar to the ones used in stirling reactors. This allows it to operate under the harsh conditions of the moon. The overall weight of the reactor is 15 tonnes (based on the hyperion reactor) so it fits within the maximum payload of the rocket system. The cost of such a reactor is $100 million or £77.6 million. Thus the profit made on mining the helium 3 accounts for the large cost of the reactor. The combined two reactors can easily sustain both the mining operation as well as the water extraction.

Solar energy problems:

Orison has decided to not use solar energy as a means of supporting the mining operation. The mining operation needs 70MW for 14.5 mins per week therefore 6×10^{10}J per week. This is not feasible as this would require around 250000 solar panels (using a power output of 265W). While solar panels would receive a stronger intensity of light from the sun, the main issue is that they don't produce a constant flow of energy due to the harsh light dark cycles of the moon. Furthermore one mars rover experienced a problem of having lunar dust on the panels thus reducing the power output.

Power = energy transferred/time taken
∴ 70MW = energy transferred/870sec
∴ energy needed per week ≈ $6x10^{10}$ J

Food solution for base:
Our bodies require multiple categories of nutrients. An important type are macronutrients - they are a type that we require a lot of to stay healthy - and are present in most fats, proteins and carbohydrates. Vitamins and minerals that we eat are micronutrients - which we don't need a lot of, but are necessary to maintain good health.

Maintaining a healthy diet on the Moon is thankfully not too different to maintaining a healthy diet here on Earth - calories need to come from different food sources - roughly 60% carbs (potatoes, etc..), some proteins (in our case from beans) and much more.

Vitamin D:
Vitamin D is made by your skin when you are exposed to sunlight. Obviously on the moon - natural sunlight is not a possibility because the moon has no atmosphere meaning no radiation protection. Vitamin D is found in foods such as fish, milk, cereals. It is required for bone structure and absorbing calcium. Therefore the only way to resolve this issue is to bring very large quantities of Vitamin D in their vitamin tablet form.

Vitamin K:
This is one of the most important vitamins that humans require and luckily for us the best source of it is in most vegetables. Vitamin K-rich foods include Broccoli, Spinach and Kale. The reason for its importance is blood clotting - Vitamin K is essential in it - and in its absence - someone could easily (eventually) bleed to death from a relatively small injury. This vitamin is also important for bone health - research shows that Vitamin K helps bones make essential proteins that hold the calcium in your bones in place. Sort of similar to Vitamin D - but essentially Vitamin K can't do its work if there is no Vitamin D to digest the calcium in the first place. The most efficient way of providing this resource however is through tablets once more.

Other Vitamins:

Every single different vitamin is crucial for your body to function at (if not close to) 100% efficiency. Vitamin K and D have already been scrutinized for their importance in bone health, but we need to make sure that our moon base population are provided enough of the other important vitamins as well. A third vitamin that is at utmost importance here to have large quantities of is Vitamin C - this is the vitamin that prevents scurvy - a deadly illness if not treated. Luckily for us, Tomatoes, Broccoli, Brussel Sprouts and Sweet Potatoes, all vegetables we plan to grow, are rich in Vitamin C. Other vitamins such as Vitamins A, B6, B12 and E will likely need to be supplied as tablets

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Minerals:

Calcium - a mineral our bones require to be strong - something we luckily will have in reasonable quantities. Without it - our bones develop a condition called osteoporosis - basically the bones become extremely brittle. However reduced/artificial gravity produces less pressure on the bones because they are not having to withstand the gravitational force of Earth - but rather of the Moon - whose gravitational force is about ⅙ as strong as the Earth. Also the bodies ability to absorb calcium is decreased in space - so our population on the Moon is going to need slightly more calcium than required on Earth to counteract this.

Iron - another important mineral required for transporting oxygen in our blood through the haemoglobin and distributing the oxygen throughout our body. Lack of iron leads to constipation and tiredness. Iron deficiency is caused by a lack of iron in the diet and can lead to extremely severe anemia. Anemia caused by iron deficiency can lead to impaired brain development in children and some adults.as with the other sources of food iron would need to be provided through tablets (<20mg/person/dose) of iron supplements.

Vitamins-Only Plan

An idea was initially thought of to just have our population in the Hab receive all their nutritional benefits from vitamin tablets. While the benefits of this means that no space needs to be dedicated to growing plants meaning the Hab is smaller and costs much less to construct - As vitamins don't supply the essential proteins and carbohydrates food will still need to be provided in other ways, however the tablets will work very well for providing the multitude of vitamins and minerals that will be impossible to provide through agriculture on the moon. So therefore we have decided to use this to supplement our growth.

Liquid Diet Plan:

This was an idea that when researched didn't seem too far-fetched. However a major downside to this plan is the fact that humans can usually only operate on a liquid diet for a very short period of time - this being that liquid diets are often used as a temporary measure because it can cause severe malnutrition in the long term. The full liquid diet is generally only prescribed for a few days to help you transition back to your normal diet. It's rarely required for longer than two weeks. However some modern powder based liquids can sustain humans for weeks. This works very well as emergency food and in the initial setup of the base as if taken properly can give all the required nutrients.

Plant-Based Plan:

Potatoes

Brussel Sprouts (excellent source of protein given meat will be in little-to-no supply - high in Vitamin C)

Other Food/Nutritional Requirements:

Vitamin D due to limited time spent in sunlight/B12 other supplements and vitamins for pretty much everything.

The artificial light is planned to come from ceiling lamps, due to the harsh light dark cycle of the moon, this artificial light would be powered by a variety of LED's which require very little energy.

We would recycle the water for continuous use for the plants. We would do this by converting the waste-water into water that can be reused. We could potentially do this by having a sewage treatment 'building' on the moon, which would also produce substances (such as ammonium nitrate) which can be used for fertilisation of the soil. ~1 square meter of plants, will use 4-6 litres of water a day. So we will need 160-240 litres/day to start off with to feed the plants (and that's the bare minimum amount).

However water behaves differently in low-gravity situations - it clumps together - making it difficult to grow crops. One of NASA's solutions is growing plants in clay rather than soil. Unfortunately plants grown in clay require a lot more water than plants grown in soil (81 litres/sqm2 compared to 4-6 litres/sqm2 in Earth soil) - This is mostly due to the fact that earth soil is already wet so needs less water clay would work better

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Pros/Cons of Growing Plants on the Moon

Pros:

- Reduces weight required on the transports for ration packs - all we need to bring are plant seeds, soil, etc...
- Fresh-grown vegetables will be healthier to consume than pre-cooked meals that are several days old

Cons:

- Takes up a lot of space - would likely be the largest section of the Hab.
- Would need almost-constant monitoring

Calculations:

Assumption of Average Calories/Person/Day: 2500

So we need to grow the rough equivalent of:

50000 calories/day for 20 people
125000 calories/day for 50 people
250000 calories/day for 100 people

Area and Resources Required:

Crop Name	Area for 1 plant	Calories/ 100g	Calories in 1 plant	Plants required (minimum is for ~15-20 people)	Total Area	Costs
Broccoli	18in plants, 24in rows	34	205	Minimum 15-20	>6.985m (for a row of 15 plants)	£18.49 for 500g of seeds
Spinach	1in plants, 14-18in rows	23	7	Minimum 50	>1.27m (for a row of 50 plants)	£1.99 for 400 seeds
Kale	3in plants, 18-24in rows	49	33	Minimum 25-30	>1.905m (for a row of 25 plants	£1.49 for 600 seeds
Sweet Potatoes	12-18in plants, 3ft rows	86	1344 (12 potatoes)	Minimum 20-25	>6.096m (for a row of 20 plants at 12in apart)	£2.25 for a bag of 3x Sweet Potatoes
Tomatoes	24-36in plants	18	810 (4.5kg of tomatoes)	Minimum 10-15	>6.096m (for a row of 10 plants at 24in apart)	Varies (e.g £2.50 for 50 seeds)
Green Beans	2-3in plants, 18-36in rows	31	67.5 (217.75g/bean)	Minimum 20-25	>1.524m (for a row of 20 plants at 2in apart)	£2.99 for 15+ seeds of green beans
Carrots	1in plants, 24in rows	41	25	Minimum 20	>0.508m (for a row of 20 plants)	Varies (e.g £2.65 for 400 seeds)
Brussel Sprouts	18-24in plants, 30in rows	43	8/sprout	Minimum 15-20	>6.858m (for a row of 15 plants at 18in apart)	Varies (e.g £1.99 for 200 seeds)

This shows some examples of how much space plants may need to grow.

Total Area for All Plants

Absolute Minimum 8m x 5m (40m squared) to have extra space for humans to move around.

Overall

Plants, especially potatoes could be a good solution for us to provide the bulk of energy however will need to be supplemented by shipments of food to and from the moon.

Due to the scale of crops needed to grow enough potatoes for a minimum 20 people being quite large this will happen later on after the rest of the base has been built. Before this time all food will be provided in either a liquid diet or packs of food similar to what is used on the iss currently.

Genetic Modification:

Without regard to the gene combinations you may introduce into a plant, it will always use an X amount of nutrients from the soil. A fast growing crop might deplete the soil faster from its nutrients. Thus, the problem will always be soil fertility or soil depletion. By introducing a synthetic plastic substitute for soil, we will be able to replenish Micro-nutrients. The provision of Macronutrients for plants does not present such an issue. The company FuturaGene has developed GM eucalyptus and poplar trees that contain genes that alter the structure of plant cell walls to stimulate the natural growth process, with primary test analysis showing a 35%-45% increase in yield. This will be our main target and focus upon the moon and will certainly be viable within the next 10 years given the current growth in expertise, funding and consistent field research.

A GM eucalyptus tree that can withstand adverse temperatures was developed in 2010. The GM tree contains a cold-inducible promoter driving a C-repeat binding protein from Arabidopsis thaliana. Selected transgenic lines were tested in 21 replicated field trials across eight different locations with various freezing temperatures. Transgenic freeze tolerant eucalyptus can grow up to 52.4 feet at 16.8oF, compared to the control trees which grew only 0.3 feet.

Gene guns (also known as biolistics) "shoot" (direct high energy particles or radiations against target genes into plant cells. It is the most common method. DNA is bound to tiny particles of gold or tungsten which are subsequently shot into plant tissue or single plant cells under high pressure. The accelerated particles penetrate both the cell wall and membranes. The DNA separates from the metal and is integrated into plant DNA inside the nucleus. This method has been applied successfully for many cultivated crops, especially monocots like wheat or maize. Research into the possibility of genetically modifying plants, particularly via biolistics, has shown that this will be commercially possible within the coming decade at the current and proposed rates of testing and field analysis. The plants on the moon will be grown in houses designed to replicate conditions on earth as closely as possible. However GM crops will be needed to withstand temperature variation/temporary malfunction, mild radiation and possible alterations made to the synthetic soil substitute.

Bioluminescence:

Bioluminescence is the production and emission of light by a living organism. It is a form of chemiluminescence. Bioluminescence occurs widely in marine vertebrates and invertebrates, as well as in some fungi, microorganisms including some bioluminescent bacteria and terrestrial arthropod such as fireflies. In some animals, the light is bacteriogenic, produced by symbiotic organisms such as Vibrio bacteria - in others, it is autogenic, produced by the animals themselves. Orison proposes to use this process in order to reduce the necessity for excess artificial lighting and hence energy which could be better stored or provided for use inside the living quarters of the HAB.

In a general sense, the principal chemical reaction in bioluminescence involves some light-emitting molecule or pigment and an enzyme, generally called luciferin and the luciferase, respectively. The enzyme catalyzes the oxidation of the luciferin. We propose to incorporate the firefly luciferase gene in order to create a transgenic crop population capable of photons emission within the grow house, due to reactions with oxygen obtained from the electrolysis of hydrogen-reduced regolith (water). Because of the diversity of luciferin/luciferase combinations, there are very few commonalities in the chemical mechanism. From currently studied systems, the only unifying mechanism is the role of molecular oxygen, though many examples have a concurrent release of carbon dioxide. For example, the firefly luciferin/luciferase reaction requires magnesium and ATP and produces carbon dioxide (CO2), adenosine monophosphate (AMP). The structures of photophores, the light producing organs in bioluminescent organisms, are also being studied in conjunction with genes which code for the enzyme responsible for the regeneration of luciferin. The largest benefit to Orison, besides the luminescence itself is the production of CO2. Plants within the grow house will be in a Carbon rich environment due to the process carried out by the plant. In turn this obviously provides more oxygen for eg. HAB residents.

The French company Glowee provides evidence that this concept will be a practical reality within the next ten years. Luminescence periods of over 16 hours have already been achieved.

Plant CO2 requirements and O2 production:
Humans consume 550 litres of oxygen per day on average. Plants produce 22 litres for every 150 g. This means with the minimum number of plants (~175-200) outlined above - they would produce 3850 litres of oxygen/150g of growth which isn't enough to support only 7 people. Due to us wanting to have 20 people from the start we will rely more heavily on the O_2 production talked about later. On the CO_2 front - we are in a similar situation - the amount of CO_2 exhaled by humans will not be enough to support a full section of the Hab filled with plants so we are going to require extra CO_2 (external CO_2 tanks could also be a possibility but also the CO_2 from the Helium 3 extraction).

Life support systems:
For the astronauts on the moon base to survive they need all of the basic requirements of humans, the most important of which is water, oxygen and food (food is covered elsewhere). As humans take in nutrition they also pass out waste such as carbon dioxide, faeces, and urine,and as they are living on the moon they need these to be reused as it would be costly and inefficient to bring up one use items and then dispose of them back into space.

Water:
Before even getting to the water reclamation system we need to cut down on the amount of water that is wasted just from general everyday usage by strategically planning the places that water can be reused from. In order to cut down on the use of water by each astronaut, they will obviously need to ration the amount of water that each of them are able to use for non-essential reasons. First off we can greatly reduce the amount of water used by putting a

limit on the amount of water used for bathing, and switch from water taps to wet cloths to reduce the water used. We can then use that 'dirty' water as a grey water supply that can be used to flush the toilet and also water the plants. Due to this rationing alone astronauts on the ISS have been able to reduce their water consumption from 50L per shower(on earth) to 4L to wash, and use less than 1/10th of the water humans on Earth use to wash their hands.

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Different water reclamation systems:

ISS - The ISS Water Recovery System (WRS) includes the Water Processor Assembly (WPA) and the Urine Processor Assembly (UPA).

The Urine Processor Assembly uses urine from the astronauts and distills it to a more concentrated version, this is done by a rotary distiller, this is used due to the lack of gravity on the ISS and so it wouldn't need to be rotary on the moon, however due to its efficiency it is one of the best options. In the distiller they use very low pressures and high temperatures to evaporate the water to give water vapour and salts. The salts still contain a little bit of unrecovered water and so the water reclamation of urine is only about 90%. There is a new system being developed called the Brine Processor, the Brine Processor is being developed to demonstrate increased water recoveries on the ISS up to 98% which will allow for a much reduced volume of water to be transported up, and less waste produced. This technology should be available in the next ten years, as it is being sent up to the ISS for testing this year.

The distilled urine along with other sources such as the humidity condensate and waste hygiene travel to the water processor assembly (WPA). The WPA process water from all of these sources together and uses the chemical process of carbon absorption and ion exchange to remove organic and ionic contaminants in the waste water. Alcohols and other low molecular weight organic compounds which are highly soluble in water are not effectively absorbed and so are oxidised to organic acids and carbon dioxide by a catalytic reactor often called WPA catalytic reactor or Volatile Removal Assembly (VRA)

Advanced water processors being developed for NASA's Exploration Initiative rely on phase change and/or biological processes as the primary means of water treatment. The phase change technologies include air evaporation, rotary vacuum distillation processes such as vapor compression distillation (VCD), wiped film rotating disc (WFRD) and cascade rotary distillation (CRD). As these will be available in the next 10 years will will use these for the lunar base as opposed to the traditional ISS WPA as they will provide a more efficient recovery system, which means the base will require resupplies less often, and so reducing the cost of survival.

Due to urine containing minerals like nitrogen, potassium and phosphorus we can use the 'waste product' of water distillation as fertilizers for the plants. This allows us to be 100% recyclable with the waste water from urine as well as reducing our need to dispose of any excess.

This water reclamation system is designed for a closed system which, due to the regolith reduction becomes infeasible. As the regolith reduction will theoretically make 50L of pure potable water, it will produce enough water to make up the wasted water and any excess (from undistillable sources, and loss of water vapour when opening and closing doors to the outside).

Oxygen production:

Oxygen production is much easier than water production in space, this is as the oxygen can be produced solely by the electrolysis of water into oxygen and hydrogen. The oxygen can obviously be used by the astronauts, and we can use the hydrogen to react with the products of the CO_2 removal to form more water and methane. Water molecules are made up of 2 hydrogen atoms bonded to one oxygen atom, these atoms split apart when electricity is run through them, we can collect and compress this oxygen to release into the hab when necessary. This is necessary as the plants from above do not produce enough oxygen for humans to survive. As humans consume 0.84 kg of water a day, and the plants will produce 5.5

kg of oxygen per day, we need to produce 11.3 kg of oxygen per day to provide enough for the astronauts to survive.
For the electrolysis of water we need:
To break down a mole of water 237kJ is required
∴ In each mole of water we get 2 grams of hydrogen and 16 grams of oxygen
To produce 11.3 kg of oxygen per day we need:

- 11.3/0.016 = 706.25 moles of water a day
- 706.25*18 = 12.7 kg of water a day
- 706.25 *237kJ/mol = 167.38MJ per day which is covered by the nuclear reactor.

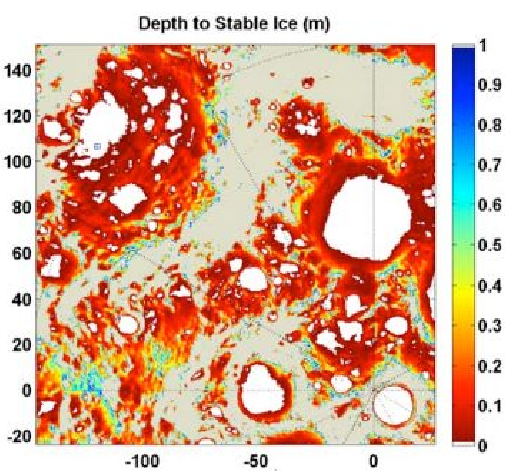
Carbon dioxide recycling:
We are planning to use the ISS system of removing CO_2, this is as the plants are unable to absorb enough of the carbon dioxide naturally produced by the astronauts. The ISS uses Zeolite beds to 'scrub' the air. Zeolite is a three dimensional crystal structure made up of silicon, aluminium and oxygen ions. The structure contains pores that are used to trap carbon dioxide and when the aluminium is removed, zeolite turns hydrophobic and can absorb other substances like VOC's. The zeolite beds are 'emptied' by heating them up as this reduces the size of the pores and so kicks out any substances that are trapped in them.
On the ISS in the CDRA they use 2 pairs of zeolite beds, one of zeolite 13x to remove the water, followed by a bed of zeolite 5A to remove the CO_2 and other VOC's. There is always one bed collecting water/CO_2 while the other bed is regenerating. As the ISS has contained at maximum 9 astronauts, we will use 3 sets of these pairs of double beds. The byproducts of this are CO_2 and water.

Combining systems:
As we want the whole base to be a fully recyclable system, we can combine some of the byproducts from some systems with byproducts from other systems, similar to the sabatier on the ISS. The biggest impact combination would be mixing the hydrogen from the oxygen production with the CO_2 in electrochemical reduction of carbon dioxide. The formula for this is: $CO_2 + 2\,H^+ + 2\,e^- \rightarrow CO + H_2O$ This produces water and carbon monoxide, the water is useful, however we will want to vent the carbon monoxide away into space as it can be deadly to humans.

We will be using vents around the hab to take in and give out the gases, all the incoming gasses will be transported through hoses to a main processing plant made up of the different systems, and then the final gasses will be taken away by other hoses and distributed around the base.

Water extraction:
The extraction of Water and subsequent synthesis of Oxygen and Hydrogen will be carried out using a combination of Hydrogen reduction and microwave beaming.

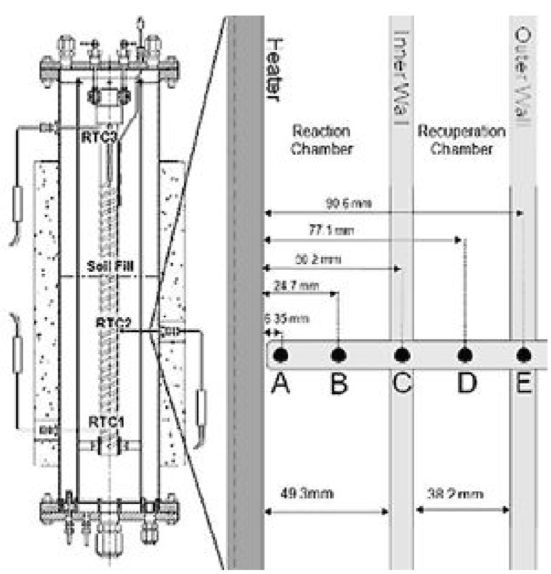
Microwave beaming is essentially a melting process, allowing us to safely vapourize approximately 98% of water-ice. It would allow us to retain and store 99% of the extracted water in a gaseous state, removing the need for drilling and mining into frigid, and often impenetrable lunar permafrost. Microwave technology remains in its infancy, however studies produced by NASA provide evidence for significant energy and financial savings compared to a process of mass excavation and heating of lunar regolith. Computer modelling technology has gone a long way into calculating the optimal frequencies for microwave beaming based upon the location and concentration of water as well as the abundance of Iron within the regolith - altering the absorption rate of the microwaves. The process in its entirety would likely be focussed upon water-rich volcanic deposits, such as those mapped by the Chandrayaan-1 orbiter (2008-2009). The distribution mapping of water 'hotspots' can be used to ensure efficiency and economical savings as we will be able to concentrate our resources into researched areas, saving time and cost. We have identified the Cabeus crater as our landing site and base of operations.



Cabeus, 100-km in diameter, and contains significant areas of permanent shadow. Such regions are of interest as they harbor significant deposits of ice (water, methane, etc). The Cabeus crater was the focus of the LCROSS Centaur impact (October 2009) that was intended to excavate and eject any volatiles that may be in the regolith. The analyses of data collected during the impact are still ongoing, preliminary results suggest that significant amounts of water ice is trapped in these shadowed regions.

A hydrogen reduction plant and lunar rover prospectors have already passed field tests on Hawaii's volcanic soil. Water mined via these methods would not only keep astronauts and plantation supplied with water upon the moon, but with oxygen and hydrogen in order to maintain living conditions within the HAB, and provide fuel for domestic lunar missions. Gerald Sanders, the directing manager of NASA's In-situ Resource Utilisation program, published a cost analysis study into the viability of hydrogen reduction. Following research into the study, it is evident that excavation costs could be returned within the first year of commercial activity on the moon. Economically, the process' upsides far outweigh the cost deficit associated with the transport of vast quantities of water and oxygen to the moon - despite preliminary mining costs and the energy necessary for the reduction reactors to reach an optimal temperature.

The process takes advantage of the chemistry of the lunar dirt/regolith. By adding hydrogen to the Iron Oxide in the lunar soil, we are able to produce water in a controlled environment. The Hydrogen Reduction Reactors heat the regolith to approximately 1832 degrees fahrenheit. The process of electrolysis is then used in order to separate the water into its two component parts - Oxygen and Hydrogen. The Hydrogen produced via the electrolysis of water will then be cycled back and reacted with FeO_2 in the lunar soil to produce water.



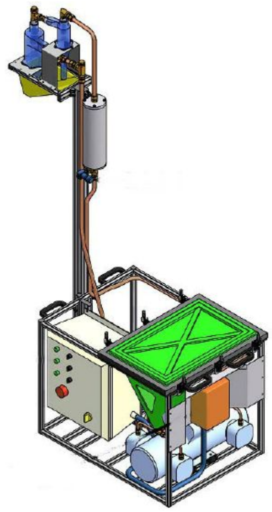
Pictured on the left is the hardware schematic for the dual chamber inside of a second generation Hydrogen reduction reactor. Concentric cylindrical chambers allow the exchange of heat from the hot regolith being processed to fresh regolith waiting to be introduced. The Regolith is maintained in a fluid and loose state (fluidization) via hydrogen flow and the vibration of the reactor.

NASA has already tested a hydrogen reduction reactor on Hawaii's Mauna Kea volcano. During a year-long operation, it produced 1,455 pounds (660kg) of oxygen from a rock-based soil containing 5% Iron Oxide. Updates in the technology involved within the reactor have made way for a second generation system which is able to produce 2,205 pounds (1000kg). The field research also led to the conclusion that their technology could be somewhat 'miniaturized,' and is something which they believe to be achievable before 2028 - satisfying our 10 year limit in developments and emerging technology. Hence Orison proposes that the reactors are placed within multiple rovers in a miniaturized state, avoiding the necessity for a single, main processing plant on the base. As the average human being consumes approximately 740kg of oxygen per annum, Orison has concluded that this method would be viable, the number of hydrogen reduction systems placed upon the surface of the moon would then be based specifically upon our astronaut count. Furthermore, the inhabitants we plan on sending to the moon would be of a smaller mass than average and will have been highly trained to withstand lower levels of oxygen as well as atmospheric differences.

Proposed PILOT Hydrogen reduction reactor system

Process overview:

The regolith is introduced into the reactor by an auger at the bottom of a hopper.
The regolith is tumbled in a conical reactor resting at an angle similarly to cement mixers while hot hydrogen fills the space. This fluidization of the soil is important to improve the exposure of all the regolith grains to the gas.



The water produced passes through a purification module that removes contaminants (hydrogen sulfide, chloride and fluoride) that hinder the operation of the electrolyzer.
Once reacted with the hydrogen, the hot regolith is poured out of the reactor. Its heat content can be recovered to pre-heat the incoming fresh regolith.

Closed loop pneumatic regolith feed system:

In order to make In situ resource utilization (ISRU) production a reality, critical subsystems must be in place in order to ensure the infrastructure of, specifically the grow house, is capable of producing enough quantity of the given resources necessary to maintain the inhabitants and plantation at the base. The regolith feed system would be local to the grow house and would provide a constant stream of regolith into an independent hydrogen reduction reactor and electrolyser. This ensures that the maintenance and condition of the reduction rovers will not directly affect the HAB or grow-house conditions. The method of pneumatically conveying lunar regolith becomes a viable option in the case of ISRU oxygen production since a gas exchange/circulation system is already required for the ISRU chemical reactors being considered for oxygen production on the moon. In addition, pneumatic conveyors involve no moving parts during the transfer of regolith particles thus reducing the risk associated with mechanical breakdown.

Commercial activity

Resource Acquisition:

Regolith Processing Potential:
Lunar regolith is a mineral-dense dirt-like substance that covers the entire surface of the moon. Abundant in (e.g.) oxygen and aluminium, this material appears to be invaluable for the Orison operation.

Overview:
The mining of aluminium on the moon will be essential to the construction of the lunar base, and will tie in directly to the commercial venture, the mining of helium-3. The extraction of lunar regolith will be accomplished through the means of remotely operated mining vehicles. (ROVs) The regolith will
then be refined at the moon base.

ROV design:
The ROVs will be driven by four brushless electric motors in each wheel, powered by lithium ion batteries, in a small pressurized and regulated chambre (as conventional lithium ion batteries don't work on the moon). The lunar regolith will be recovered by means of a bucket loader on the front of the vehicle. The bucket loader will scoop lunar regolith from in front of the rover to the hopper on the rear. The rear cargo hopper will have a volume of 9 m^3. (3*1.5*2) The mass of such a load in regolith is 13.5 tonnes. The bucket used will be modelled on that of a . The power pack (here referring to the engine and batteries) and the chassis (£38,200) will be modelled on a modified version of the Tesla Cybertruck. (Payload on moon: 9525kg, which shall be modified to 15000kg) The charge time is 44mins, will add an hour for checks and fifteen minutes for handling and plugging in of the ROVs. (requires 2400 KWh per 24 hours)

The total amount of regolith brought back in every trip, due to a load of 9 cu metres per rover, with six rovers functioning at one time, making approximately 1 trip per hour.

Aluminium oxidation:
Lunar regolith is made up of almost entirely anorthosite, a type of plagioclase feldspar that consists of mostly anthorite, the compound that will be used. The percentage composition of anthorite is as follows:

0.41% Na (*Sodium*)
13.72% Ca (*Calcium*)
18.97% Al (*Aluminium*)
20.75% Si (*Silicon*)
46.14% O (*Oxygen*)

Due to a lack of clear figures (thanks to almost all lunar regolith remaining on the moon) it shall be assumed that the lunar regolith is 70% anthorite. The anthorite will be reduced at the experimental building on the lunar base, using the FFC Cambridge process (in short, a bath of molten $CaCl_2$ is used, with the anthorite being the cathode, and using a carbon anode) The process takes place at ≈1270^o K, so a large amount of energy will be required for the process. One advantage of being situated on the Moon is a minimal heat loss via conduction into the atmosphere and ground. The energy required will still, unfortunately, be high. The energy consumption of the FCC Cambridge process is circa 33 KWh per Kg Al output. One tonnes of regolith will result in a product of 189.7 Kg of Al, 461.4 Kg of O, 137.2 Kg of Ca and 207.5 Kg of Si, in order of importance to the mission. The reduction of one tonnes of regolith will therefore require 6260.1 KWh of energy.
Provisional power requirements for mining: 65000 KWh per day.

FFC Cambridge Process Breakdown:
The FFC-Cambridge process was first based on the reduction via electrolysis of TiO_2 to pure titanium in molten calcium chloride ($CaCl_2$), and has been applied to reduce a variety of metal compounds, particularly oxides, to their respective metals, alloys and compounds. In the

process, the pre-shaped metal compound (Forming of anthorite pellets will have to be conducted in the reaction building) is attached on a cathode which is then electrolysed against a suitable anode under a cell voltage that is high enough to ionise the oxygen in the metal compound without decomposing the electrolyte. The FFC-Cambridge process can be represented by the following reactions where M represents a metal.

Overall reactions:

$MO_x(s) \Rightarrow M(s) + x/2O_2(g)$ (inert anode)
$nMO_x(s) + xC(s) \Rightarrow nM(s) + xCO_n(g)$ (carbon anode, n = 1 or 2)
Cathode reaction:
$MO_x(s) + 2xe^- \Rightarrow M(s) + xO^{2-}$
Anode Reactions:
$xO^{2-} \Rightarrow x/2O_2(g) + 2xe^-$ (inert anode)
$nO^{2-} + C(s) \Rightarrow CO_n(g) + 2ne^-$ (carbon anode, n = 1 or 2)
See schematic of FFC process below.
Note - the metal produced normally has a porous and interconnected structure
One of the problems with the FFC Cambridge process is that the metal tends to form perovskite phases while being reduced (in-situ perovskitization) which kinetically retards the process. Possible solutions to this include ex situ perovskitization with any O^{2-} e.g CaO.

Building Requirements for Mining Process:
FFC Process:
A building will be required in which to conduct the FFC process. The calcium chloride bath will need to be heated to 1045°K to conduct the process, which will require in-situ heaters. An area needs to be dedicated to the formation of the anthorite pellets for the cathode - this process can be automated and is estimated to require 36 m^2 of building area. The area required for the bath, heaters and milling of the solid (metal sponge) product is estimated to be $100m^2$. An area will be required for the storage of the product and, if necessary, forging of the product. The power requirements of the forge will be based on desired output. A closed-die forging technique will be used, with the aluminium being heated to 815° K for the process. The power requirements of forging five tonnes of aluminium plates will be roughly 85000 kWh, requiring a 3542 kW supply over a 24-hour period.
Provisional total power requirements: 150000kWh per day, as a steady supply of 6250 kW.

Mass of equipment required
ROVs:
The ROVs will have a base mass of around 2.5 tonnes, with additions of roughly one tonnes, giving an estimated mass of around 3.5 tonnes each. With an estimated nine being taken to the

Moon, a mass of 31.5 tonnes will need to be lifted. The batteries for the ROVs will also need to be taken, (Based on the Tesla Powerwall 2) and their estimated mass is 122 Kg - 9 will be 1.098 tonnes. Total for ROVs: 33.5 tonnes

FFC Cambridge Process:

Roughly 150 tonnes of equipment are required for the FFC process and the forging of the aluminium.

Total:

182.598 tonnes for all processes.

Extraction of Helium 3 from Lunar soil, for shipment back to earth to be sold commercially: Value, background & applications:

Emitted from the sun, Helium 3 cannot reach the surface of Earth, as it is prevented by our magnetic field and atmosphere. However in Lunar soil, there are trace quantities of the isotope, as due to the lack of atmosphere on the moon, it is bombarded with atoms from the sun constantly. Hence, it is estimated that in the first few meters of Lunar dirt *alone*, there are over one million metric tonnes of the isotope, with total estimates ranging up to five million tonnes in total.

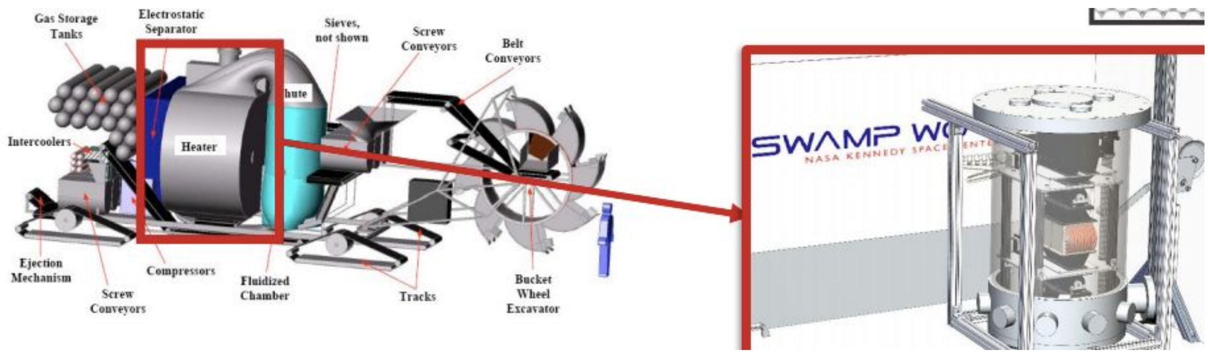
With the current global supply sitting at around 15kg/annum (produced as a byproduct of maintaining nuclear warheads, from the decay of tritium) the gas sells for around £2.29bn per tonnes*. The scarcity is not the only thing that drives its prices however: promising research and experiments in ^{3}He fusion suggest it could aid in solving the Global energy crisis. Releasing proportionately larger amounts of energy than deuterium/tritium fusion, without making the surrounding reactor components radioactive; it is obvious that the chemical has importance in modern science and is worth extracting commercially. At current predictions of expected power outputs from ^{3}He fusion, it is said that the equivalent of a space shuttle cargo bay (around 25 tonnes) of the chemical, could power the USA for up to 4 years.
In addition to its fusion potential, ^{3}He behaves in a different fashion from regular helium at lower temperatures, giving the gas a potential application to the advancing field of cryogenics.

Proposed extraction method & requirements for operation:

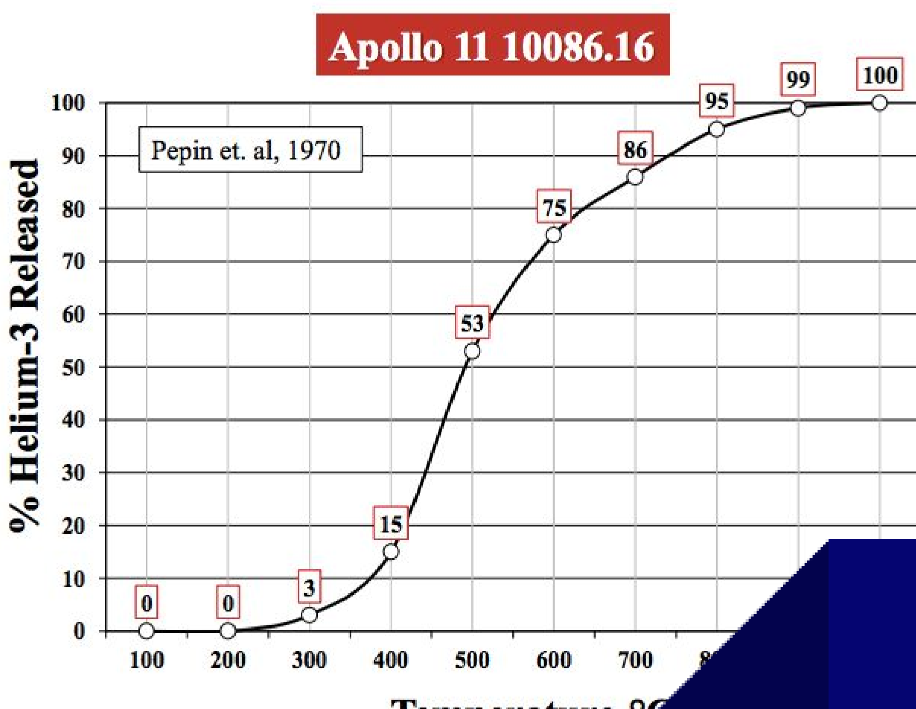
Operating on the £2.29bn/tonnes market price of ^{3}He, Orison aims to meet a 500Kg/10 week shipment programme back to Earth. This schedule is expected to create an operational turnover of over £5bn/annum.

Orison proposes to implement a previously-researched NASA method of ^3He extraction, which involves using counterflow heat pipe exchangers to raise regolith temperatures to 600 degrees celsius, causing the subsequent diffusion of ^3He gas from the Lunar dust, where it is then compressed for transport. To begin this process, large volumes of Lunar regolith must be drilled: One cubic meter of regolith has a mass of approximately 1,500kg, and ^3He is found in concentrations of 512,000 parts per billion of each cubic meter of Lunar topsoil (determined by a global inventory of ^3He in lunar regolith, estimated by a multi-channel microwave radiometer on the Chang-E 1 lunar satellite). One billionth of a 1,500kg mass is 1.5 milligrams of ^3He, hence 512,000 billionths is approximately 0.77kg of He3 content per cubic meter of regolith.

The regolith will be sifted, then run through a machine designed and built by NASA researcher Aaron Olsen, at the Fusion Tech. Institute of Wisconsin-Madison. While Olsen's design (seen below) contains the heat exchanger and compressor apparatus within a mining vehicle, the aforementioned Orison rovers will carry out the regolith collection independently, and the ^3He will be extracted on-site at the Orison habitat module. Olsen's technology can be seen here:



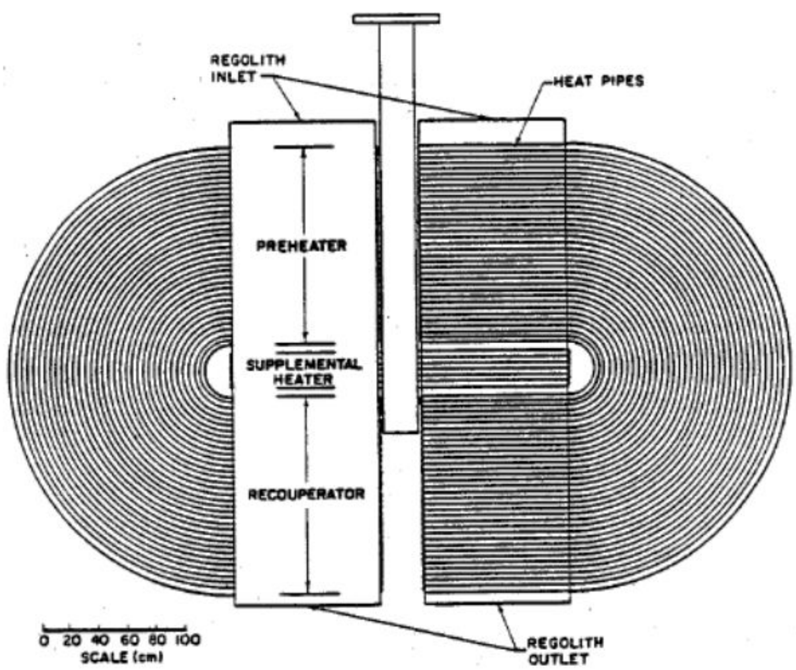
Orison plans to utilise the components highlighted in the box above, in addition to larger gas compressors to store the ^3He in 10Kg capacity tanks. The density of ^3He at liquid is 59g/L,



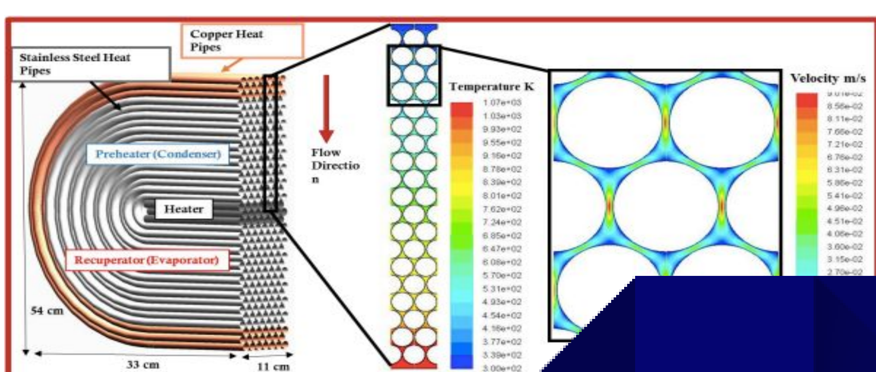
meaning that Orison will use compressed fluid tanks of approximately 170 Litres in capacity, to store the proposed 10Kg of ^3He/tank, meaning that each tank will contain 0.17 cubic meters of ^3He.

When heating the regolith, the proposed temperature (as previously stated) is 600 degrees celsius. Whilst the graph (right) shows that it is more heat-cost-effective to heat the material at 500 degrees, Orison has elected to heat at slightly greater temperatures, to increase the total yield of ^3He.

As shown above, the 600 degree temperature results in a 75% ^3He yield, resulting in a total yield (from the previously mentioned average 0.77 total ^3He per Kg within each cubic meter of Lunar regolith) of 0.57Kg/cubic regolith meter. Hence, to maintain the sustainable ^3He mining process and schedule, around 18 cubic meters of regolith are required to fill each 10Kg capacity tank. 50Kg of ^3He/week is required to maintain the tonnes/20 week proposed programme, hence around 90 cubic meters (135 metric tonnes) of Lunar regolith is required to be mined on the Orison site each week.



A heat exchanger of such proposed size is capable of heating 157Kg of regolith (from 30 degrees C, to up to 700 degrees C) every second, thereby showing that processing time of the regolith is no issue for the Orison schedule. The exchanger requires a 70MW power supply to run, however will obviously not need to run constantly. In fact, if the exchanger were to run constantly every week, the operation would (in theory) be able to process over 700 times more regolith than required. At

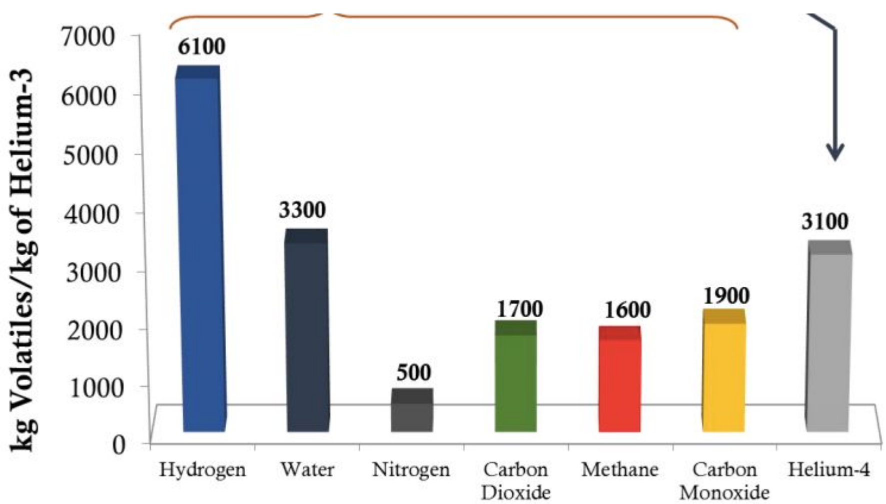


Olsen's stated peak performance rate of 157Kg/s, the exchanger would have to run for a little under 14.5 minutes a week. Therefore, Orison is not concerned about the high power consumption of the essential component for this operation.

The on-site exchanger uses a combination of water in copper pipes (operating up to 250 degrees celsius), mercury in stainless steel pipes (operating between 250-500 degrees), and sodium operating (over 500 degrees), to cool the heating components, and return roughly 85% thermal energy into the next load of regolith.

Further releases:

In addition to ^3He, The Olsen process also releases a high number of valuable volatiles, that have many applications to the additional activities Orison proposes. Per Kilogram of ^3He, over 0.9Kg of Hydrogen gas, 1.1Kg of water, 1.6Kg of Nitrogen, roughly 0.8Kg of carbon dioxide, methane and carbon monoxide, as well as up to 1Kg of Helium four. methane, hydrogen and water all have valuable applications in fuel manufacturing, as well as the carbon dioxide, nitrogen, methane and water having life support potential. Helium four is also a valuable commodity on Earth, and has huge potential in the field of cryogenics.



On Orison's weekly schedule, the Olsen process will therefore produce the following:

45kg of Hydrogen
55kg of water
80kg of Nitrogen
40kg carbon dioxide, methane & carbon monoxide
40-50kg Helium four

All these extra chemicals aid in making the Orison mission as self-reliant as possible, and thus reducing mission cost. Any produce stated above that has no use to the operation will simply be vented out of the site: Waste is no issue.

Costs:

The primary cost of the mission will be the heat exchanger and gas cylinders, which should cost no more than £350,000 (with the exchanger estimated to cost up to £150,000). Being relatively small in size, the mass of the exchanger and canisters combined will be under 500Kg. See the above report on resource acquisition for cost information on the ROVs. With the operation (when compared to income generated) being as cheap as it is, and with so many benefits to the mission, the ^{3}He mining operation will be a definite commercial success, and allow Orison to fund the mission, whilst monopolising the global ^{3}He supply for years to come.

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