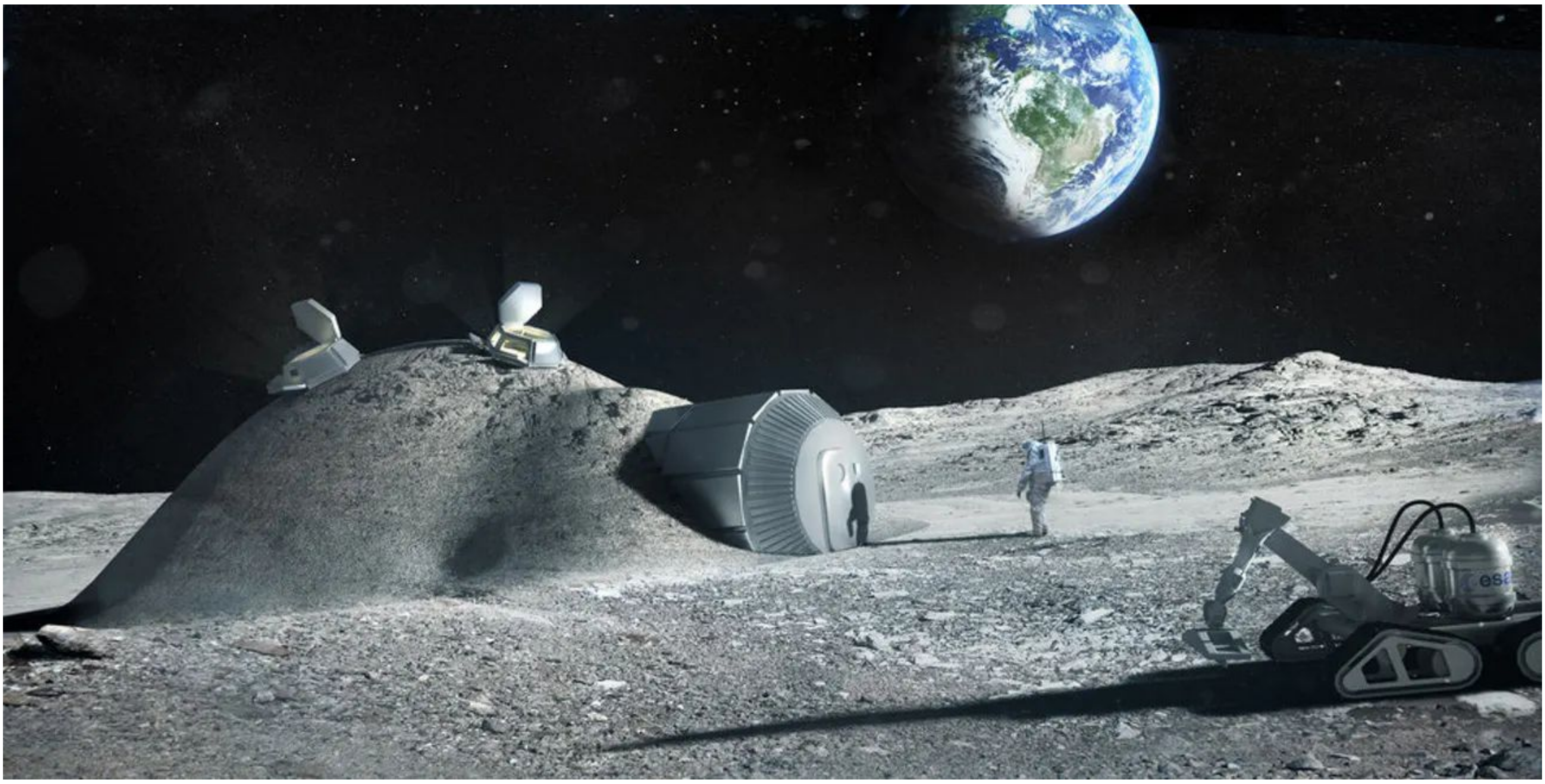
Blott Matthews challenge:
Lunar for Living



Barton Peveril College
By Harry Williams, Evan Goldstone, Rapha Kwiatkowski, Dylan Homewood, Zac Looker and Sohail Sumra

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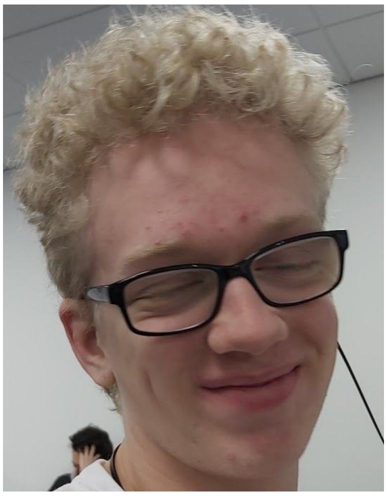

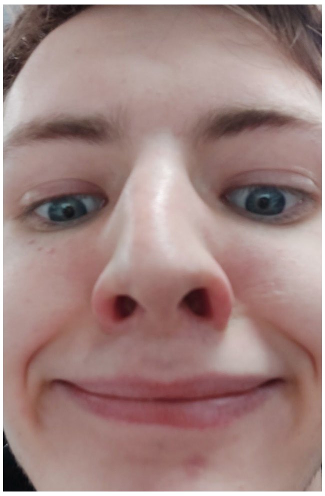

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Strategy and Aims

The moon. For years regarded as a god watching from above, a shimmering silver sentry watching as an unfathomable symbol of the unknown. Then as time went on, as scientific knowledge and methodology developed we began to view it not as a deity but as a challenge to our ingenuity and innovation. A challenge we took on with the Apollo missions in the mid-20th century. Since then the moon has shone on still as a challenge to humanity, the next step in the evolution of our technical prowess.

We are planning to revolutionize the space exploration industry-as well as quite a few others-by creating the first premium industrial and research facility on the moon, for the use of countries and private company around the world, to innovate and explore this new world that has sat sentry over us for as long as we have had eyes to see it.

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Enterprise

Our business model and strategy is simple. Build a functioning base on the moon equipped for scientific research and development, for everything from mining to satellite launches.

Last year, 60% of the funding for SpaceX came from government contracts. This sets a precedent for high levels of state funding for privately run space exploration. By pulling funding from both private corporations and worldwide governments we could move our species to the next stage of it's evolution, with very little start-up capital.

What would they be paying for?

They would be paying for use of cutting edge facilities and premium research opportunities. With large enough living spaces to house up to 40 people, their research would be hindered only by their imaginations.

Telescope's and Cosmological Photography

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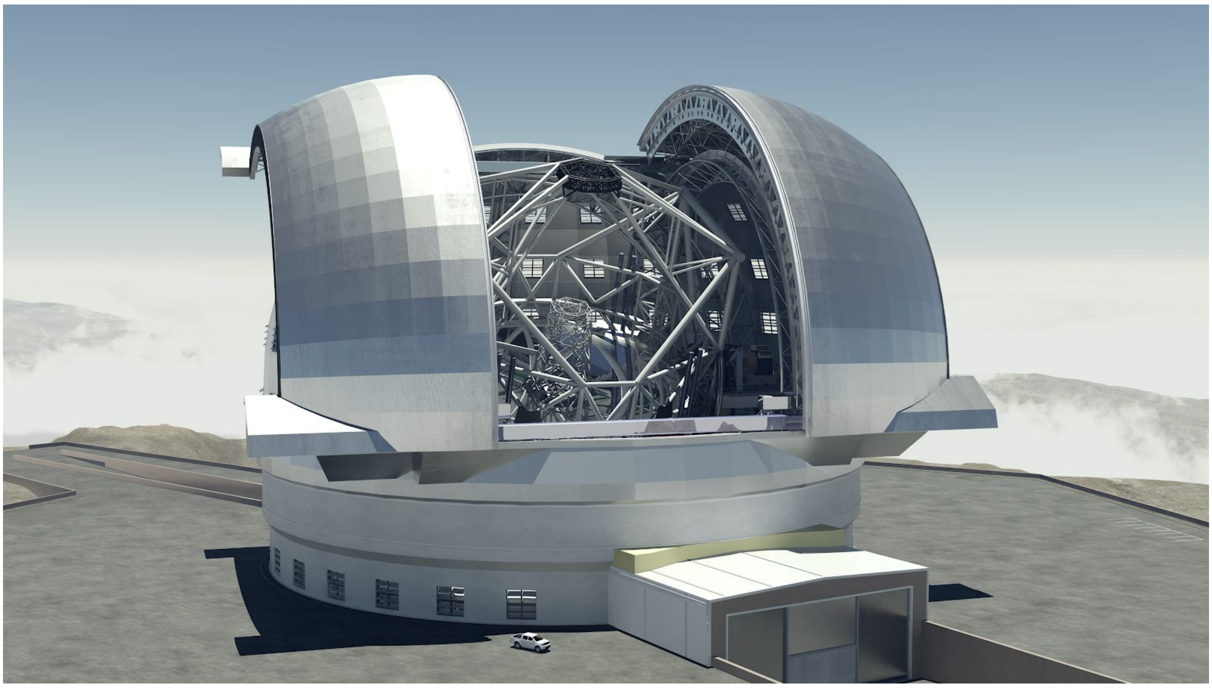

Even in the least populated areas of the world, light pollution still plague's high grade telescopography, limiting their accuracy and crippling our ability to research our universe. However a telescope array on the moon would eliminate this problem. And with the final mission of the hubble telescope, the earth needs a new premiere research telescope. An array on the moon would be just as powerful as the highest magnifying telescopes on Earth, able to provide high quality unpolluted photos of the planets in our solar system and beyond.

Such a telescope would not only be available to the residence of the base and their associated research groups/states, but time on it could also be rented out to earthbound researchers like universities and even private citizens.

Rocket Manufacturing and Launches

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The moon's gravitational field is almost an eighth of the Earth's and there is no atmosphere to speak of. This combined with the repositories of water at the poles makes it an ideal spot for a space port for launching rockets for interplanetary exploration for governments and private companies alike.

By building the rockets in our state of the art factory, and accommodating exploration personnel, who traveled to the moon via our proprietary Space hook system, our base would become a one-stop-shop for refueling, recuperating and launching new missions to the deeper fathoms of space.

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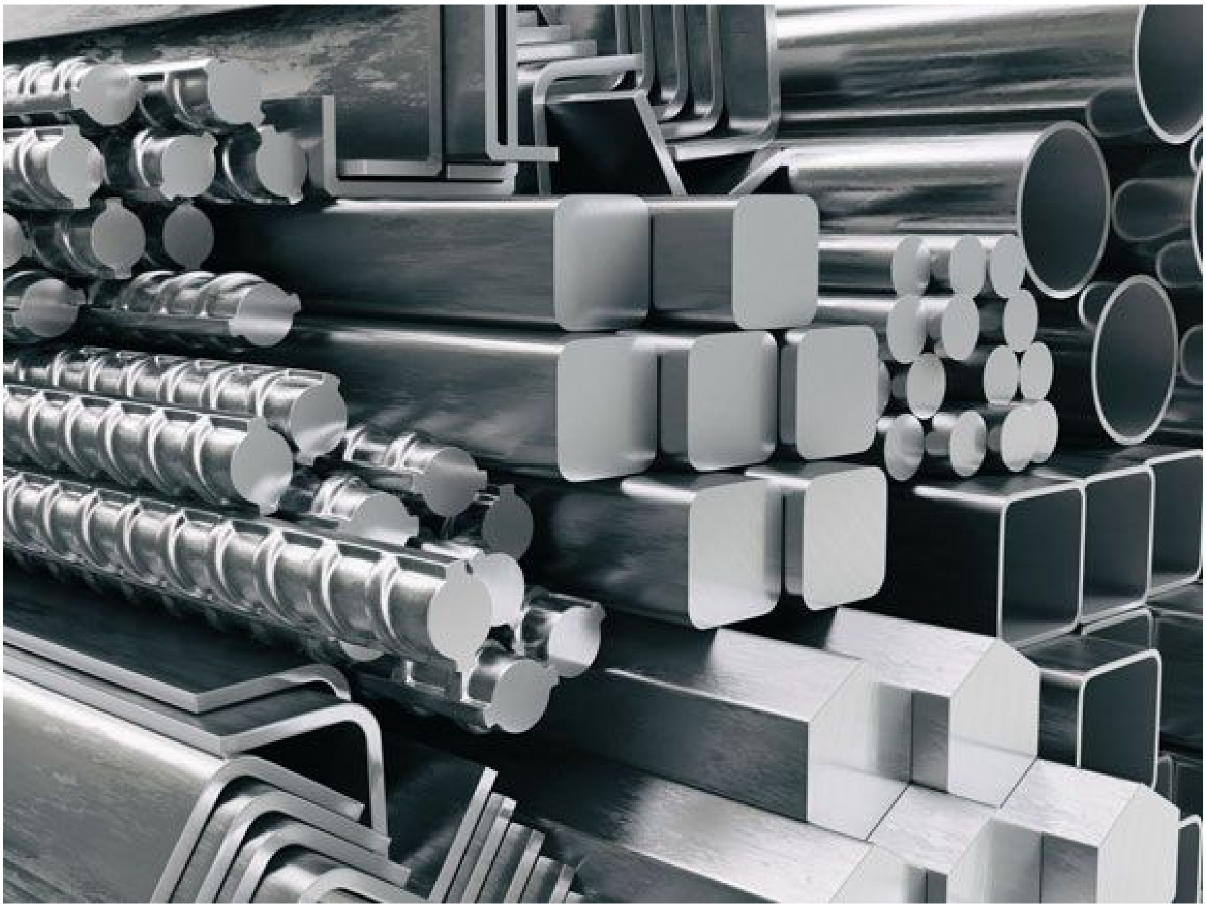
Living space

Materials:



For a moon base to survive in the harsh environment of the moon where temperatures range from -183 degrees Celsius at night to 106 degrees Celsius during the day. There are also large amounts of radiation due to there being no atmosphere to absorb the rays. This means that we will need to use materials that are strong and insulating.

Firstly we will need a large amount of concrete for the foundations of the moon base. However, this large amount of concrete can actually be produced on the moon, this greatly reduces the amount of resources we need to transport. To produce Lunarcrete™ moon dust can be used as an aggregate and liquid sulphur as a binding substance. Both of these materials are abundant on the moon as sulphur can be purified from moon dust. Moreover the Lunarcrete™ can be made on demand as it is being made on the moon. Although we will need a facility to produce the Lunarcrete™ it will require a lot less materials to be transported to the moon.

For this we could have an aluminium alloy, specifically 7075-T651 aluminium alloy as it has a high young's modulus and a tensile modulus of 570 MPa. Not only is it strong but it is also reasonably light, with a density of 2.810 gcm^-3. This makes it the perfect material to create the shell of our base out of.

Titanium alloys could be used as the main structural supports of the base, particularly the grade 5 Titanium alloy

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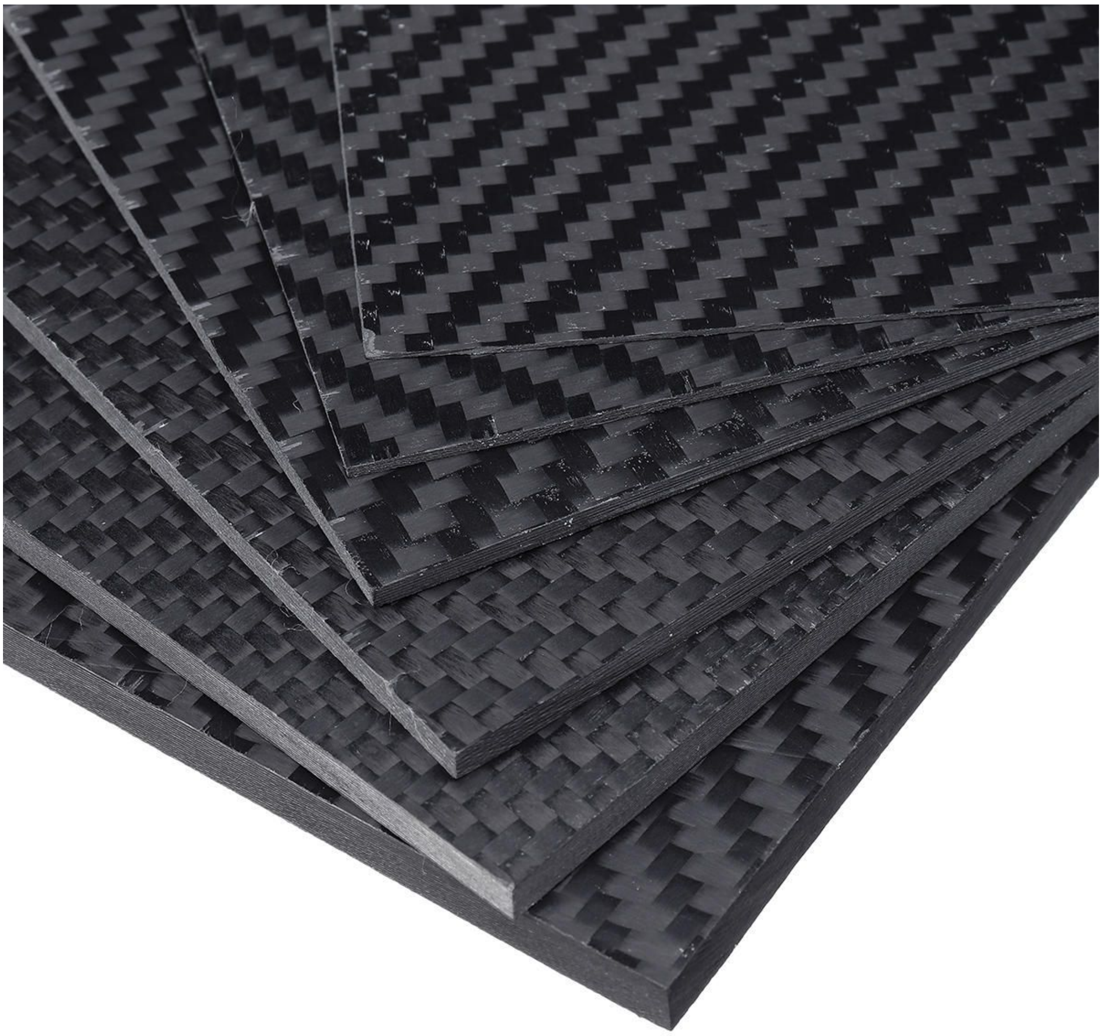
Ti 6-4, this alloy has a density of 4.42 gcm^{-3}, a young's modulus of 120 GPa and a tensile strength of 1000 MPa.

The windows in the shelter will need to have an inner layer of tempered alumino-silicate glass, also known as pressure glass, this is to help keep the pressure low inside the shelter. The outer layers will need to be made of fused silica glass to withstand extreme temperatures.



Food and water

The recommended daily intake of water for a man is 3.7 litres and for a woman is 2.7 litres. However we will also need water for sanitation 20 litres per person per day, and agriculture. Moreover the recommended calorie intake for a man is 2500 and 2000 for a woman.

To produce the required amount of water per day, which is an average of 464 litres per day for 20 people, we could use a number of methods: the first method is the recycling of condensation on the moon base; another is to recycle the urine produced by the inhabitants; runoff can also be collected. All of these options would obviously need to be purified. These methods are all used on the International space station, they produce 16.4 litres of purified water per day, however that is only with 6 people and a much smaller station. With a station of our stature with 20 inhabitants the recycled water produced per day could be at least 50 litres of water.

However there are a number of ways that we can save water. We can use the urine produced by the inhabitants to help water the farm; for every 1 part urine it has to be 10 parts water else the plants will perish.
Hydrogen fuel cells could be used as a source of energy and a source of water, the water cannot be used for drinking until

it has been purified. However it can still be used for cleaning and watering the farm.

A farm will be necessary for sustainable living as it will provide a constant flow of , therefore reducing the amount of food that needs to be sent to the base. A foodlarge farm can also help with managing the oxygen and carbon dioxide levels of the base. The most vitamin rich vegetables are as follows: spinach, broccoli, potatoes and carrots. These plants all require loose, fertile soil that is slightly acidic; every plant besides potatoes also requires moist environments. Carrots and potatoes also need full sunlight but potatoes shouldn't be grown in the same place for 2 years as it can cause disease.

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Oxygen:

One of the major issues is something that we take for granted every day, Oxygen. Firstly the chemical make-up of the atmosphere in our living space should be exactly the same as the atmosphere on Earth; 78.09% Nitrogen, 20.95% Oxygen, 0.93% Argon, 0.04% Carbon Dioxide and traces of other gases. This means that all of these levels must be kept relatively constant. To begin with this is not a major issue as we can simply transport canisters full of the Earth's atmosphere which can then be used to fill the temporary living space and permanent living space with breathable air.

However the entire time we have people living in these habitats they will affect the atmosphere of the habitats. The average person consumes 0.84kg of Oxygen in a day or 590 litres, this takes up 0.59 cubic metres in gaseous form. This means that, for one day for 8 people in the temporary living space we will need 6.72kg taking up a volume of 4.72 cubic metres. Therefore we will need to transport 201.6kg of oxygen taking up 141.6 cubic metres for thirty days of survival. 141.6 cubic metres is a very large volume, luckily there are a number of ways to reduce this. To begin with we can transport the oxygen as liquid oxygen, this has a density of 1141 kilograms per cubic metre. The result of this is that 141.6 cubic metres of gaseous oxygen becomes 0.124 cubic metres of liquid oxygen. Obviously this comes with its challenges, liquid oxygen must be kept below -183 degrees celsius, but if it is well insulated then it shouldn't be an issue.
For the final moon base this means that 20 people will require 16.8 kilograms of Oxygen per day, taking up 11.8 cubic metres. To supply them for thirty days this means we will need 504 kilograms in a gaseous form, however this only takes up 0.441 cubic metres in liquid form.

Yet there are even more ways we can reduce the amount of Oxygen we need to transport. Waste water can be turned into oxygen by purifying it and using electrolysis. This produces pure oxygen and hydrogen gas:

$$2\ H_2O \rightarrow 2\ H_2 + O_2$$

This means that for every one oxygen molecule produced two hydrogen molecules are produced. This means that an electrolysis system working at 50 kilowatt hours produces 1 kilogram of Hydrogen and 8 kilograms from 9 kilograms of water. The expected amount of waste water is at least 50 litres per day, meaning that it is possible that we will not need to transport oxygen. Using 22.5 litres of water will produce 20 kilograms of oxygen which is 3.2 kilograms more than the expected necessary amount. This does however mean that we will have less purified waste water for sanitation and consumption but water is safer to transport than liquid oxygen.

Location:

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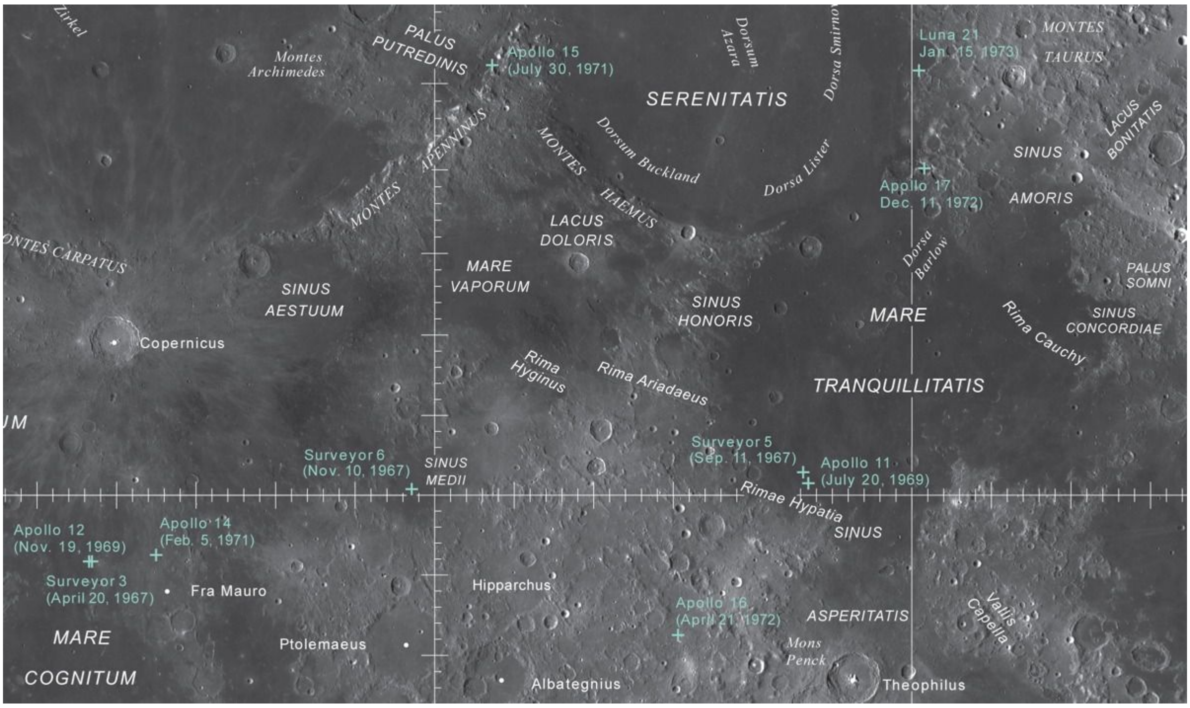
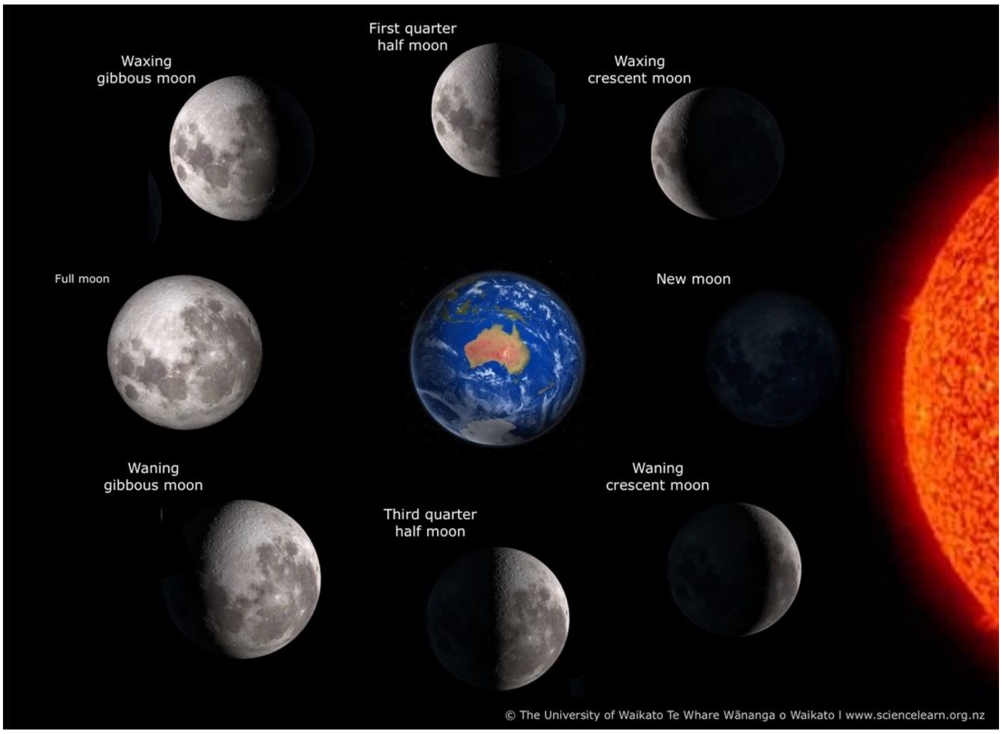


One idea of where we could build the moon base is in a lunar lava tube. These are formed by cooled lava creating a hard, sturdy lid above an ongoing lava stream. This creates a tube like space that can be under 40ft of basalt and could be as wide as 500m before becoming unstable. A potentially similar lunar lava tube was discovered in 2011 and was photographed by the lunar reconnaissance orbiter in the marius hill region. As they can be formed under 40 ft of basalt this could be a viable area for human habitation as it would lower the range of temperatures from -183 degrees at night and 106 degrees during daytime to an average, stable temperature of -20 degrees celsius. Which is liveable with some extra insulation in the moon base. This also protects the astronauts and the moon base from meteorites, radiation from cosmic rays and solar flares. In this location we would have to have the launch pad and solar panels above ground. We may also have to support the lunar lava tube as we would be placing it in an unusual amount of strain and we don't want it to collapse. Also as we wouldn't want to chance that the tube it sealed we would have to outline the tube in a safe, sealed and strong material for example an aluminium alloy.

A similar idea is a man-made cave. This would lower the cost of building the structure of the moon base but take longer with more labour to make the cave. This would have a similar effect of protecting the astronauts from the extreme temperatures and the meteorites, radiation, cosmic rays and solar flares etc. however this would be different from the lava lunar tube as we can choose where to dig it, therefore we can have it in a suitable location for landing and living while we build the hole and for solar panels, radio tower and farms on the surface. This will also make it so we can make the cave the shape we want, removing unwanted space or adding more space as we need it. However we would need to be careful to keep the strong structure of the cave intact as it would be dangerous for it to collapse. To stop this from happening we may have to support the cave with some support structure or pillars .

A different idea is to build a moon base above ground. This would increase the work we would have to do to stabilize and fight the extreme temperatures and keep it safe for the habitants. However for this idea we would not have to support the natural surroundings. For this to work we would have to make a sealed base made out of strong and insulating materials such as an aluminium alloy and titanium alloys for support. This location would keep the main base close to the farms and solar panels that have to be on the surface. This will help us sustain them as we can see if anything goes wrong through the pressure glass windows.

Overall we have decided to go with the moon base in the lunar lava tube. This is because it will protect us from the natural challenges on the moon, for example the extreme temperatures and the meteorites and radiation on the moon.



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Design:

The curved structure is designed to reduce strain and stress on the base. The curved space also maximises the surface area of the living space. So essentially this is one of the best designs. The tunnels will reduce the radiation from outer space. These tunnels will also be insulated so no heat will be lost and will prevent the freezing temperature on the surface of the moon from entering through the tunnels. The moon base being partly underground will help us reserve money as we do not have to invest into more materials to build extra space, or another couple of bases. If we find caves while digging underground we will use that as extra space for our colonists.

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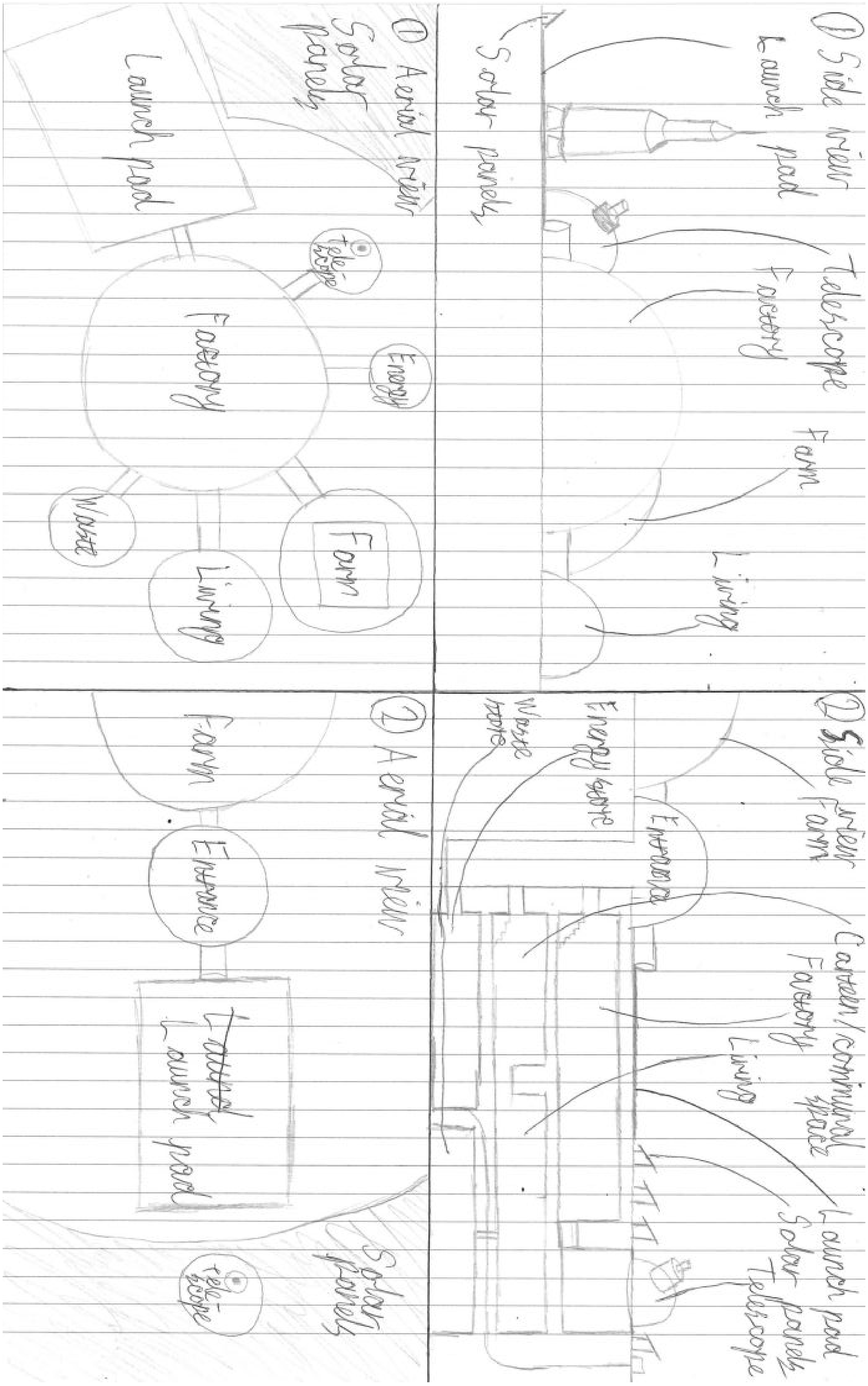

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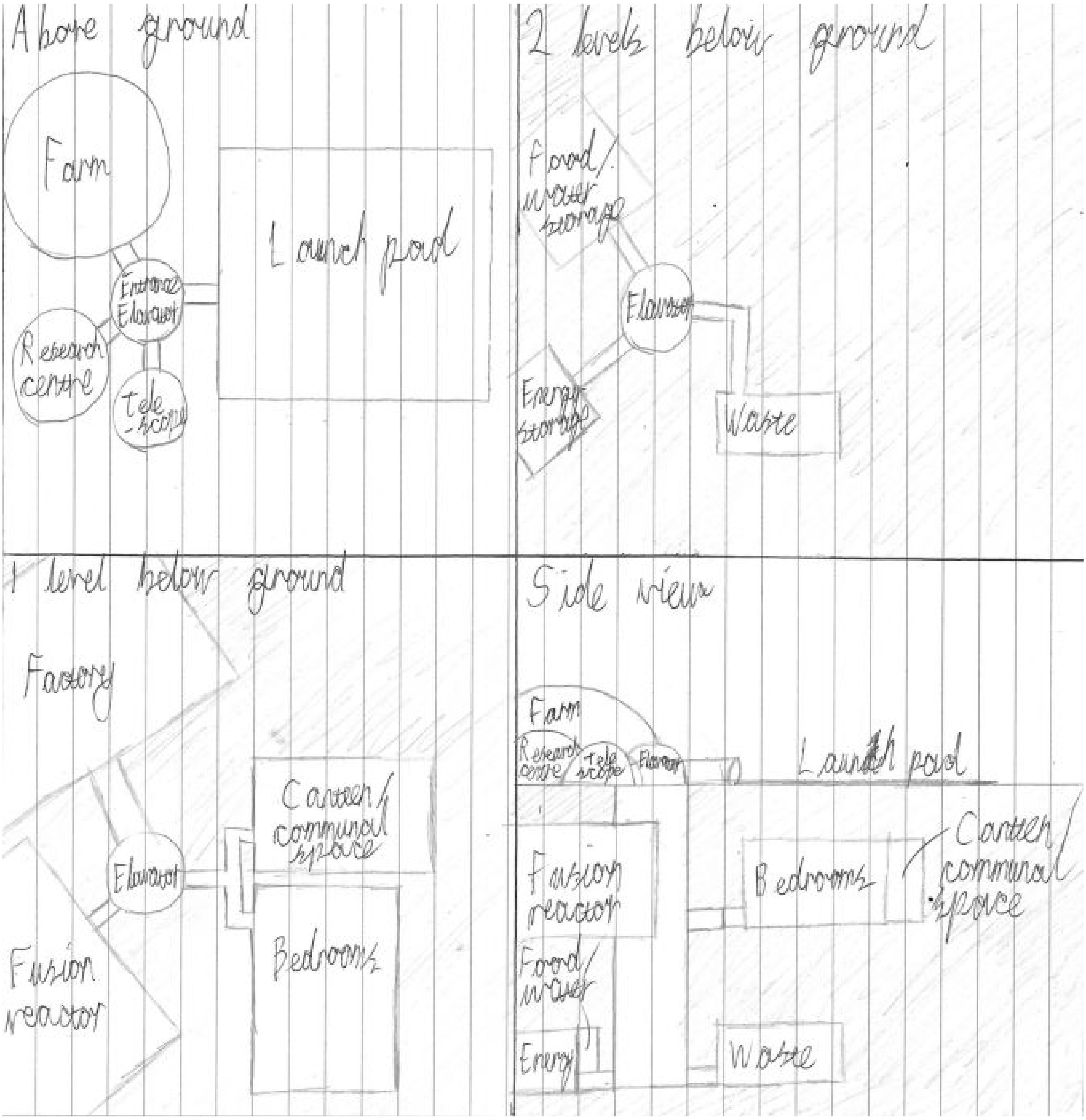

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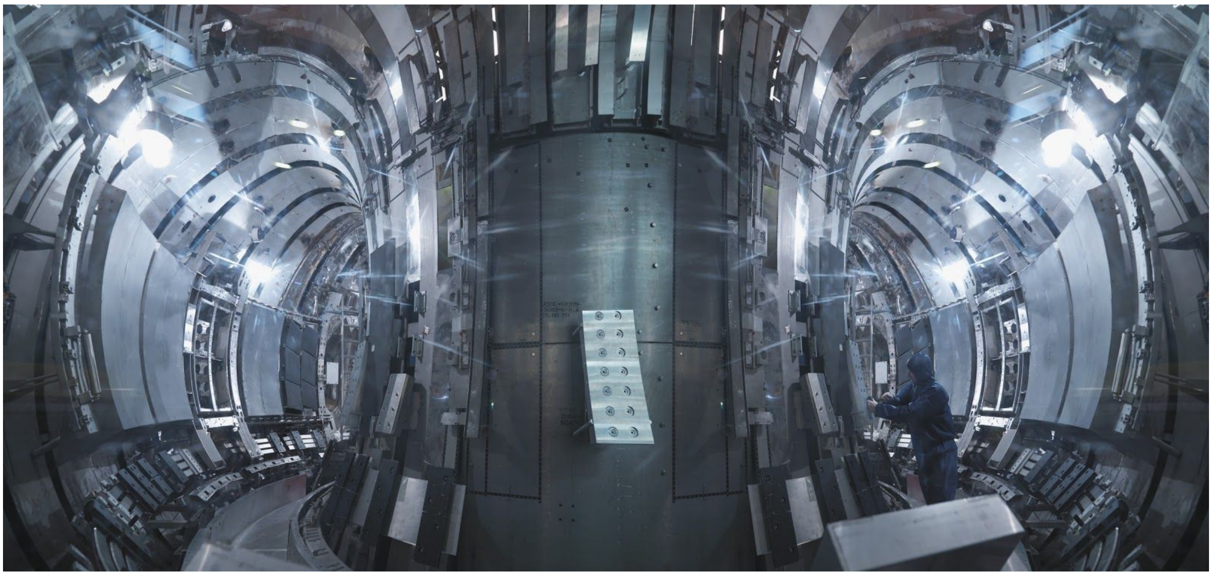
Energy

Fusion reactor:

Using coal fired-power plants would be an extremely fuel consuming and massive operation, that is why a fusion reactor is the best option of electricity production. Moreover it is estimated that fusion reactors will be a reality within ten years and the power output estimates for them are astonishing. A 1000 megawatt electric fusion power plant is estimated to produce 7 billion kWh per year of electricity or 7 GWh per year. This is enough energy to power roughly 117000 one bedroom apartments a year or half the Falkland Islands; in 2014 the Falkland Islands used 13.95 GWh.



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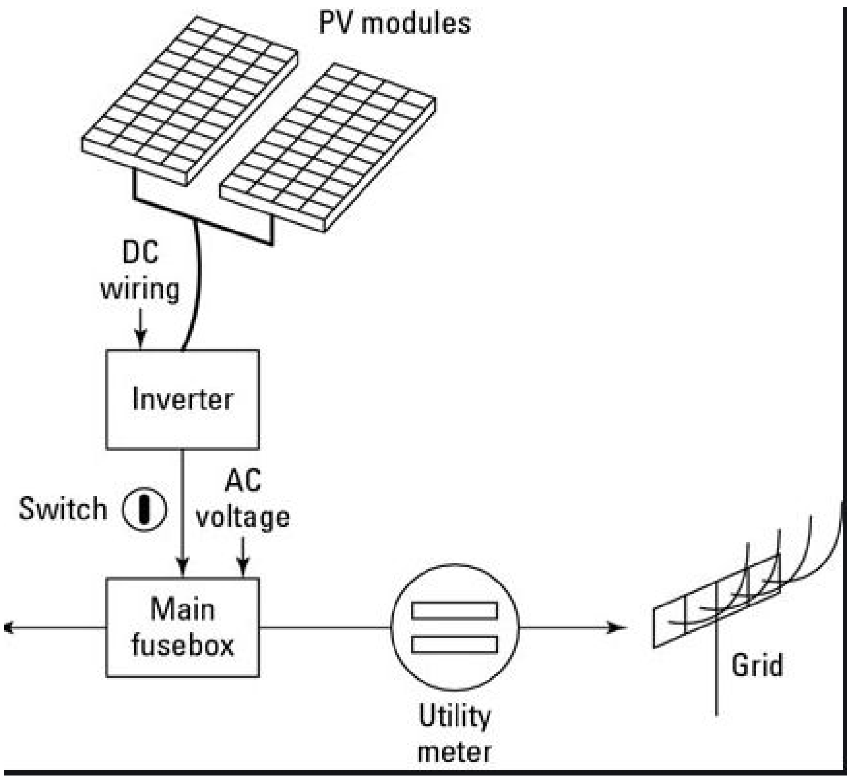
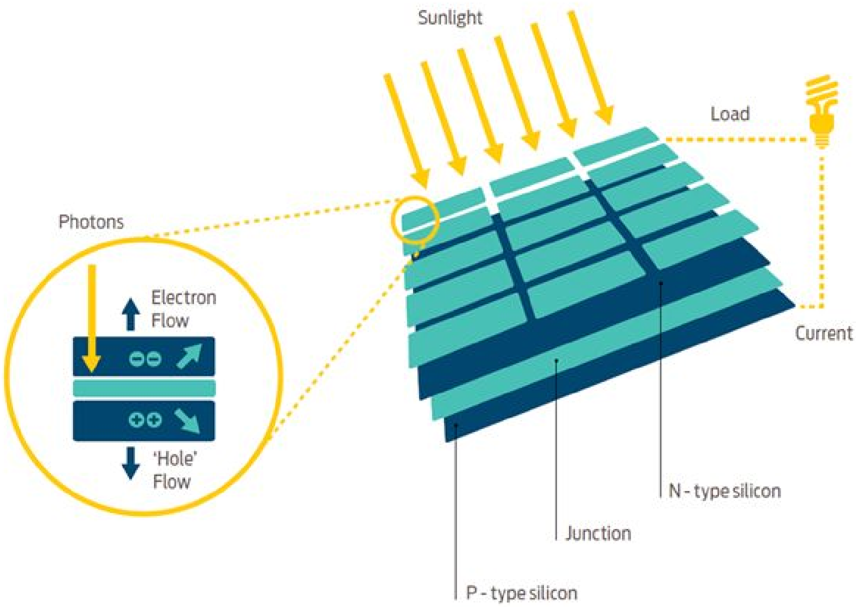
Not only does a fusion reactor produce large amounts of energy it also uses very little fuel, a 1000 megawatt reactor only uses 100 kg of deuterium and 3 tonnes of natural lithium. Whereas a coal fired power plant would need 1.5 million tonnes of coal, not only will this be incredibly expensive it will also be very difficult to transport that amount of fuel to the moon.

Solar panels:

Solar panels could be a valid alternative instead of a fusion reactor, this may be necessary as fusion reactors are not a reality currently. Furthermore solar panels would be more efficient on the Moon as there is no atmosphere so a much greater amount of the infrared radiation from the Sun will be transferred to the solar panels. On Earth a solar panel array of 400 square feet or roughly 37.1 metres squared will



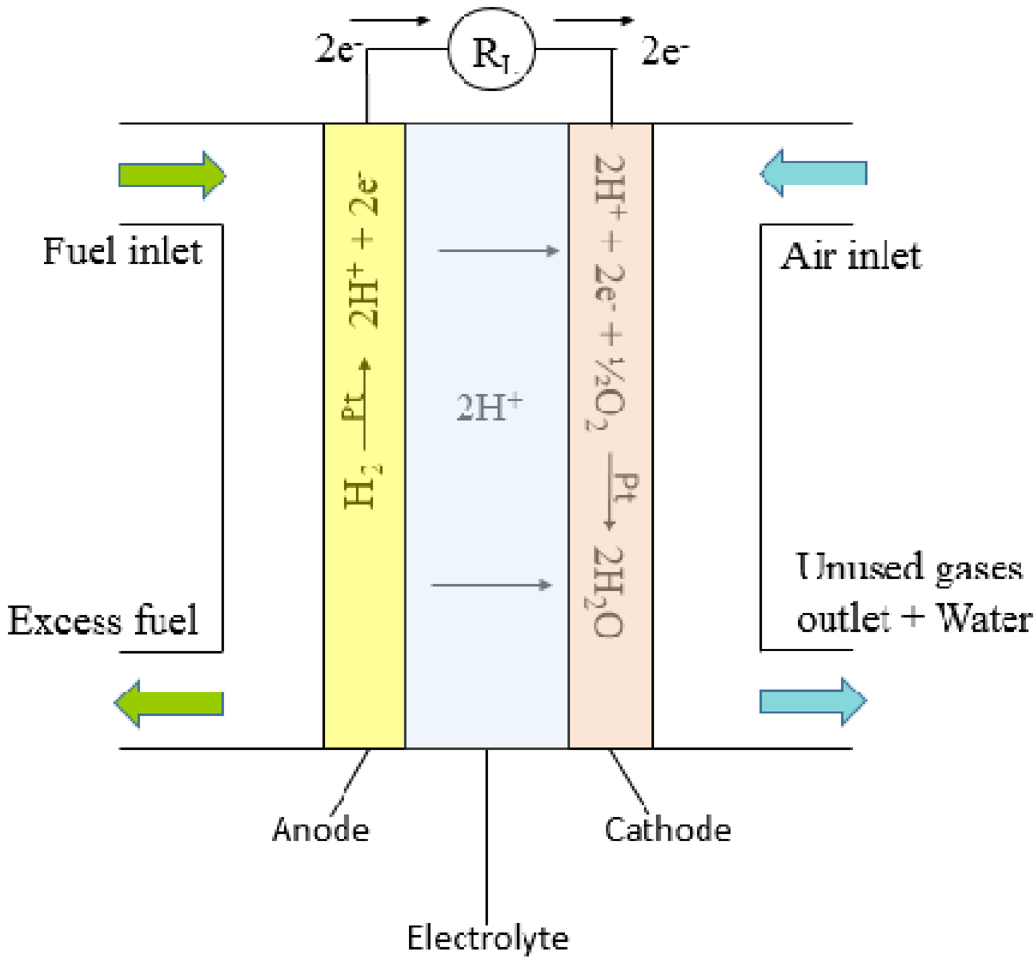
produce anywhere between 4200 and 10200 kWh per year. To produce the same amount of energy as a fusion reactor we would need anywhere between 666,670 and 274,510 square feet or 61940 and 25500 metres squared. However that is on Earth, on the moon solar panels will be more efficient as there is no atmosphere this means that a much smaller area of land will be needed to produce enough power.



Hydrogen fuel cell:

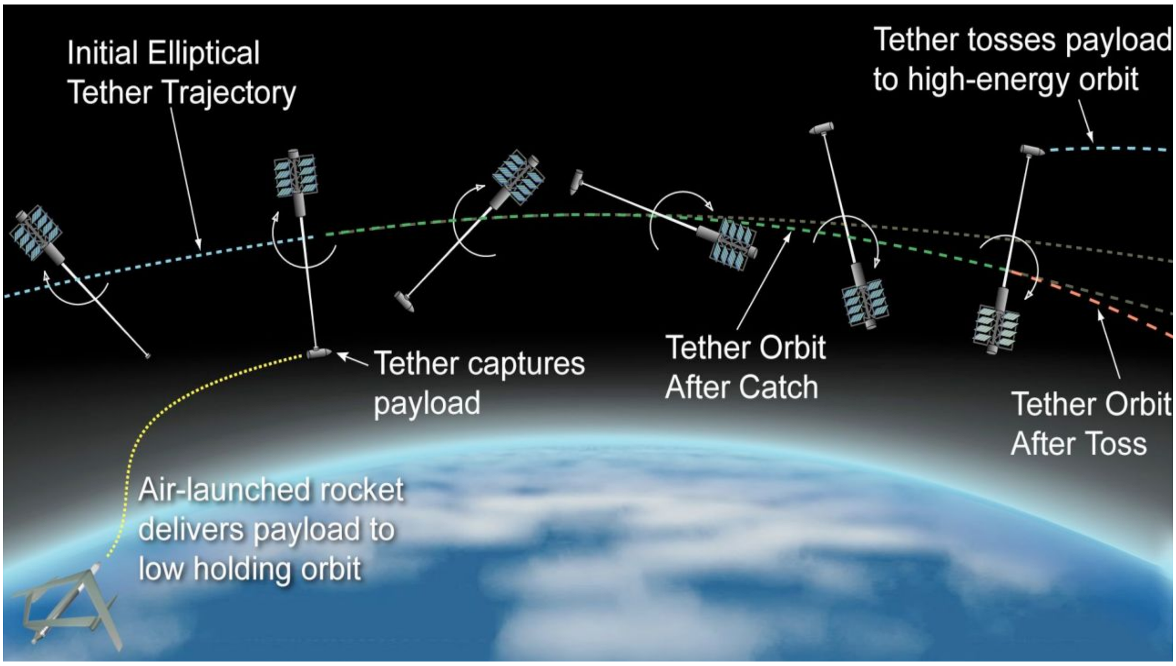
The main objective of a hydrogen fuel cell is obviously to produce usable electricity however they also produce a small amount of water. As for the amount of electricity produced;

they can be easily scaled to the size required to produce the required amount of electricity.



Transport

Space tether



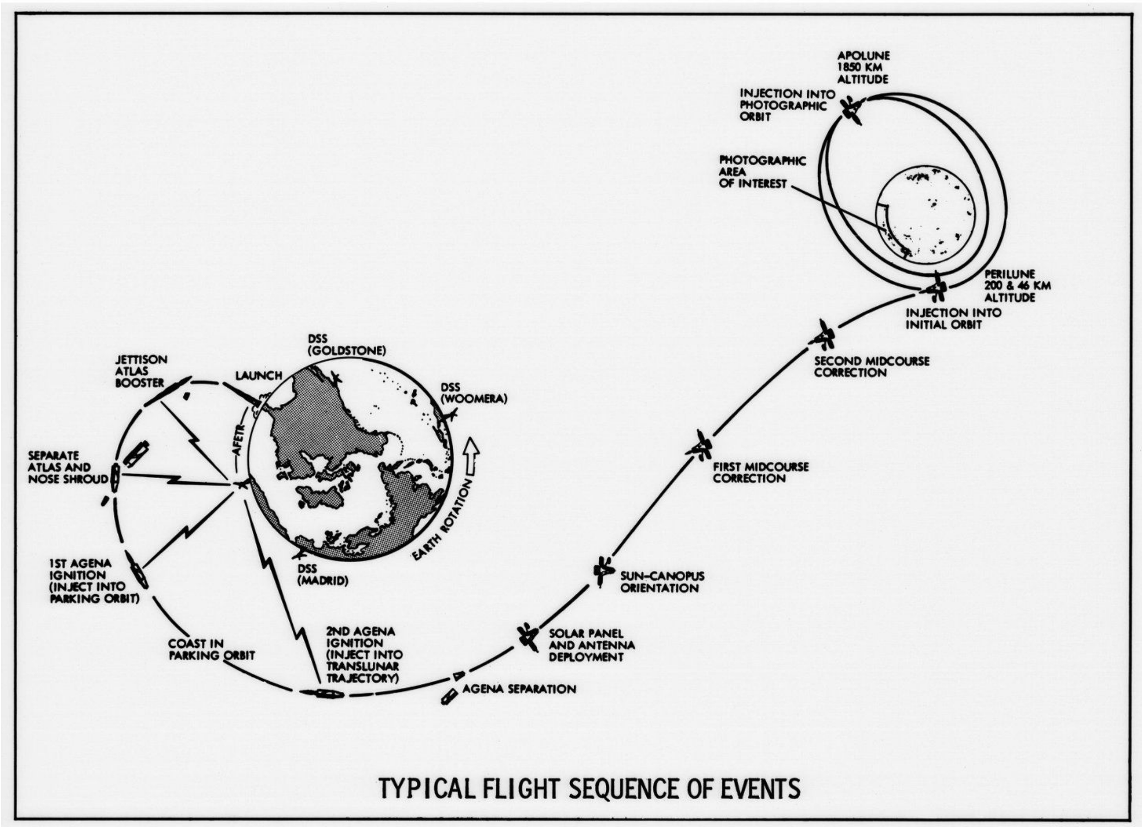
Space Tethers, (Skyhooks) are long cables in orbit that spin due to the large counterweight at the end. As it is spinning it can be used to propel things from whatever it is orbiting (i.e Earth and the moon) to another planet or satellite. The orbital velocity and the rotation of the tether are synced in such a way that the tip of the tether comes the closest possible to the surface every rotation.

The good thing about this is that it requires zero propulsion as the momentum of the space tether is what propels the payload. Unfortunately, use of the space tether to propel things from a planet will result in its orbit slowing, potentially leading to it falling out of orbit. However repeated use of the space tether both ways will transfer momentum from incoming craft to slow them down. This will keep the space tether in orbit. This is known as a momentum exchange tether and this is the most viable non-fuel based propulsion system as it is the cheapest as well as using materials available to us now. Other systems include solar sails, electromagnetics and formation flying.

Dual space tethers, with one at earth and one a the moon would allow us to reduce costs of launching payloads to the moon and would decrease the time taken to get to the moon by a significant amount, this would be beneficial because reducing the time we can get resources and manpower to and from the base is vital to ensuring that our commercial idea is successful.

Initial transport

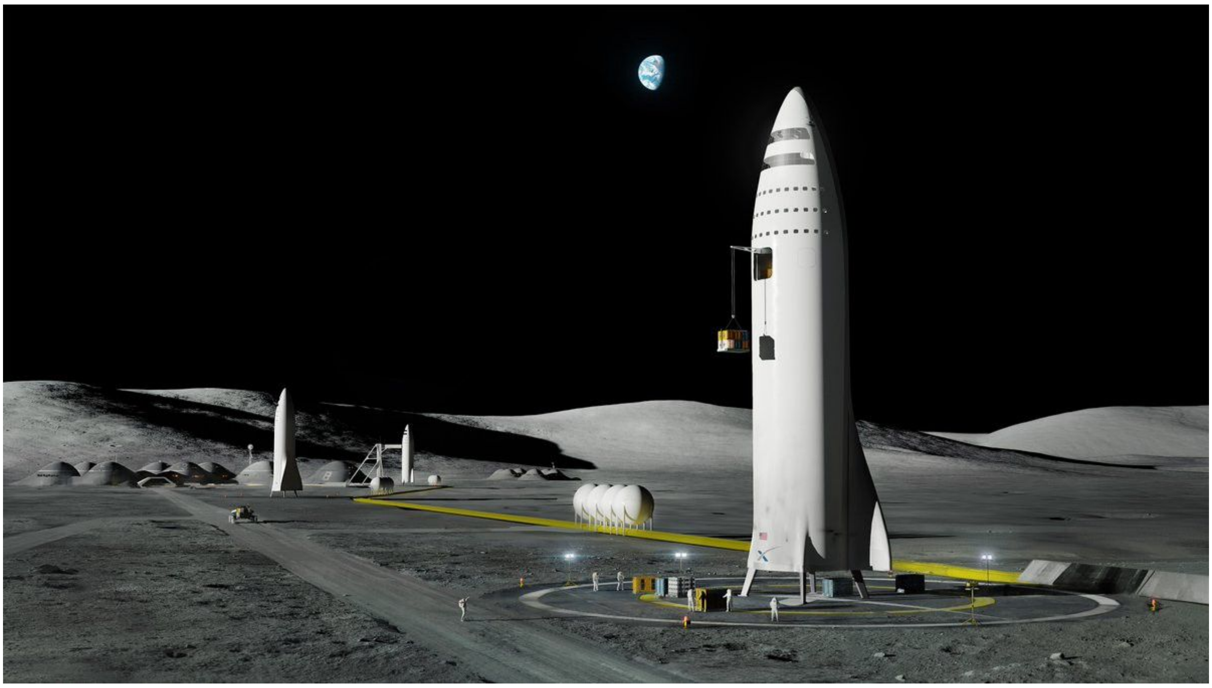
Before the space tether has been set up we will be sending up an initial team of 8 to set up basic infrastructure to accommodate the initial colonists so that they can provide the enterprise to generate income, as shown in the rocket diagram the lander will have enough space to accomodate 8 people as well as taking up necessary materials and food to prepare for the arrival of the other colonists.



TYPICAL FLIGHT SEQUENCE OF EVENTS

As shown in the diagram above the initial rockets' trajectory will be quite simple, first the rocket will enter a parking earth orbit, it will then coast towards a set point at which it will start an injection burn to create an encounter with the moon, whilst travelling away from the earth there will most likely be a requirement for a mid course correction burn which would correct the encounter with the moon to the desired orbit. If the course can not be corrected to the desired orbit in one burn (as the fuel usage would be too much) then more injection burns may be necessary.

Once the rocket is within the moon's sphere of influence then there will be a burn at the periapsis to bring the rocket into orbit. From there we can then land with the entire rocket as it is designed to function as a lander once in lunar orbit. And the lander will function as the living space for the initial colonists.



Rocket:

This is a brainstorm for the rocket designated to deliver the astronauts and engineers up to the moon. We do not plan to bring them back with the same rocket as we will provide them with a healthy living environment and enough food to last them till they have constructed the first stage of the lunar base. We will send two similar rockets up: one with the engineers, and one with the necessary resources to construct the first stage of the lunar base. The rocket is fueled with PBAN and APCP for the initial boosters and LH2 / LOX for the other stages. The rocket will be powered electrically with a 8GW hydrogen fuel cell and solar panels for the final rocket stage. The final stage is designed to be able to land on a precise location of the moon's surface.

Initial Boosters, 32,000 kN (2 SRBs)

Core Stage, 7,440 kN (4 RS-25s)

Second stage, 440 kN (4 Rl-10s)

Final stage, 253 kN (Rl-60)

We will need to transport 10,000l of water on the first flight, this takes up 10 cubic metres and has a mass of 10,000Kg, this will last 8 people 53 days.

Temporary living space:

The final stage of the rocket that we land on the moon will also act as a temporary work/living space until the first stage of the lunar base is completed. The living space, in the final stage of the rocket, comprises 7 rooms and two floors. On the bottom floor there is approximately 700m^3 of space for storing equipment and other necessary tools for construction. On the top floor there are 6 rooms all of roughly equal size. Two of these rooms are living spaces for the 8 engineers being sent up. We have ensured that there is enough space for them. The next room is an exercise and leisure room to up the quality of life and the health of our engineers. Next, there are the showers, toilets and all other necessities for sanitation. The final two rooms are designed to store enough astronaut food to last 2 years.

In Conclusion

With all of this in mind, our innovative strategies and determination to bring a new age of space exploration to civilisation is the next step in humanity's journey to the stars. The only limit is our imagination.