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Establishing a Lunar Outpost

An Interactive Qualifying Project Report

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By

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Ian Ball

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Joseph Bauer

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Andrew Dawson

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Stephen Jenkinson

<Date>

____

Professor Mayer Humi

<Section>

ABSTRACT

Our project examined the feasibility of establishing a lunar outpost. This included analysis of Earth to moon transportation, sustainability, uses for the moon, and the potential effects on humanity. We determined that the moon is a viable option for private companies to explore due to the opportunities in establishing life-supporting systems, harvesting fuel for alternative energy, and experimental studies. The lunar outpost would have its greatest effect on humanity by providing alternative energy sources and detection of near earth objects.

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EXECUTIVE SUMMARY

This project will address the feasibility of establishing a lunar outpost. As the commercialization of space continues to expand, private companies could turn their attention towards the development and maintenance of a human-manned moon base. After establishing an initial, life-supporting base, we turned our attention towards self-sustenance using lunar materials such as ice from the poles and metal from the moon's surface.

We first examined relevant historical events that pertain to establishing a lunar outpost within the last 20 years. Examining the government's most recent full-scale plan for manned exploration on the moon, Project Constellation, gave us a suitable benchmark. Then we reviewed the most recent space policy in order ensure that we would adhere to all the rules to space exploration

We examined multiple trajectories to get to the moon including Lagrangian point travel, patched conic transfer, and a hall thruster powered slow orbit. As it stands right now patch conic transfer has proved to be the most effective means of travel for both cargo and humans; however, given different parameters, hall thrusters would be useful for cargo transport and Lagrangian would be useful for both humans and cargo.

Locations for an initial lunar outpost were considered by examining the light distribution and possible water content in each spot. Locations that could prove to be useful for future projects were also examined.

We than examined the possible future projects that could be conducted after a lunar outpost has been built. These included harvesting Helium-3 as well as solar energy from space, the identification and prevention of near-Earth objects, and possible experimental work that would benefit from being conducted in space.

Finally, we estimated the initial costs of these objectives and determined the possibility of undertaking a project of this magnitude. Then we determined the ability of the lunar outpost to generate revenue. If the initial costs can be recovered in a sufficient amount of time we will then be able to determine it would be worth it for a private company to attempt and set up and outpost on the moon.

Introduction

Throughout history space has become more accessible to the curious minds of humans. As our technology improves we continue to gain access to deeper levels of understanding of our universe. From the invention of the telescope to the first manned space station, we have persistently furthered our knowledge of space. We believe that the conquest and better understanding of the Moon can push scientific advancement past what could be achieve simply on Earth. This project examined the process of establishing a lunar outpost as well as its potential use as a permanent settlement. We have investigated methods for arriving at the moon analyzing Hohmann transfers, Lagrangian point transfer and conic transfer. We studied the moons topography and other conditions and deemed the best possible initial location. We then analyzed uses for a lunar outpost. These uses included gathering helium-3 as fuel for nuclear fusion, harvesting solar energy to send to earth using wireless power transmission, the ability for the moon to serve as an observatory to track near earth objects, as well as other experimental uses that could affect humanity or create revenue. Finally we examined the effects of a lunar outpost on humanity and deemed barring any unforeseen disaster, would have an overall positive effect on humanity due to the alternative energy it could provide as well as the scientific benefits that would steam from a lunar outpost.

Ian Ball - His interest in the humanity and space IQP steams from his curiosity in cutting edge technologies especially those used in space exploration. He is a Mechanical Engineering major with a focus in design so advances in space-aged technologies would be relevant to his studies. Throughout this project the theme of alternative energy interested him to broaden his studies in the field eventual leading to his choice of an alternative energy MQP.

Joseph Bauer – Joseph chose this topic due to his interest in space, aeronautics and technology from a very young age. This interest led to him choosing to pursue an Aerospace Engineering degree. His current studies give him an excellent background for in depth discussion about propulsion and the mechanics of space travel. This project has assisted his studies at WPI because it is supplementary to topics covered in his classes. He feels that it is important to continue our search into space for various reasons, including alternative energy and further exploration of our solar system.

Stephen Jenkinson - Stephen's interest in this project was sparked by a general interest in space and a thirst to expand his knowledge on the subject. He is a Mechanical Engineering major giving him an extensive background in physics and engineering sciences. His research on this project has worked hand in hand with his studies providing a medium to use the skills learned in his classes at WPI. His work on the Interplanetary Superhighway particularly sparked his interest due to the celestial mechanics involved.

Drew Dawson - He chose this IQP because of its relevance to his major field, Electrical and Computer Engineering. There are countless products that are used in this field of study that have been developed or remodeled by an electrical engineer. He now possess a keen interest in this subject and would like to possibly seek a career in the industry. This report improved his writing and investigative skills as well as solidify his stance on where the space industry should explore.

BACKGROUND

To begin analysis of the feasibility of a lunar outpost we must look at the most pertinent developments in recent history. Humankind has not set foot on the moon since the Apollo 17 mission in 1972. The most relevant information on the subject of establishing a lunar settlement came in 2004 with Project Constellation. This project is no longer in place but provides us with the best compilation of ideas to set up a lunar outpost.

In the wake of the explosion of the *Columbia* shuttle there was a call for a clearer direction in the space program. In 2004 President Bush announced a new vision for space exploration. In this vision, the U.S sought to advance its scientific, economic, and defensive interests by starting up a large space exploration program. The President highlighted several objectives, among these were ideas to increase the United States abilities to explore and sustain life in space. The first destination in exploring the universe would be a return to the Moon by 2012. Some other objectives included using the international space station as a research center with an emphasis on understanding how the space environment affects astronaut health and capabilities as well as solutions for these problems. After exploration of low earth orbit the U.S planned on sending robots to the moon to prepare for human presence by 2008. The government also planned to hold the first extended human expedition of the moon between the years 2015 and 2020. These particular objectives would help gain knowledge, experience, and develop questions needed to establish a lunar base.

The plan created in 2004 would become known as Project Constellation and it consisted of several new vehicles. The Orion spacecraft would serve as the primary vehicle for human space exploration, carrying 4-6 people. The Altair Lunar Lander could carry up to 4 astronauts to the moon from orbit. The Altair would be launched separately from the Ares V and would join the Orion in low earth orbit. The Altair can act as a base on the lunar surface for up to seven days for initial surface exploration missions. The Ares I was the rocket behind the Orion and had a 25-ton payload. The Ares V is the rocket that will launch the Altair vehicle to orbit for missions to the moon and it would be the biggest rocket ever built.

The presidential change in 2009 resulted in a revised national space policy. The Obama administration created The National Space Policy in June 2010 that laid the guidelines for anyone's future involvement in space exploration. The reason behind the new space policy was due to the increased amount of nations and organizations using space. The high usage of space means that irresponsible actions such as pollution are bound to increase. The United States wants all nations to use space together and responsibly. The government outlines several principles that laid the guidelines they intend to uphold in outer space. Any operation in space, including a lunar outpost should be knowledgeable of this policy and adhere to its standards in order to avoid any complications.

In the United States space policy the government established an ethical standard and proposed that other nations follow suit. The government believes it is in the interest of all nations to use space responsibly, the United States considers the stability and free access to space a national interest. Space operations should be conducted in ways that emphasize transparency so everyone can benefit from space equally. The United States believes that the competitive sector is vital in order to make advancements in space and will encourage and facilitate the growth of a U.S commercial space sector to support the needs of the U.S. All nations have the right to use space for peaceful purposes that include national and homeland security. Purposeful interference with space systems such as supporting infrastructure will be considered an infringement of a nation's rights. The United States will use a variety of measures to make sure space is free and protected for all nations. Following the ethical standards they created the United States hopes to energize the competitive domestic industries of space launch technologies, satellite services, and terrestrial applications. Secondly, the U.S hopes to expand international cooperation of space. In order to make space a safer place the U.S wishes to strengthen the stability in space. We hope to collect information on debris collision avoidance in an effort to aid in the protection of critical space systems. It is also a goal of the U.S to pursue and develop new technologies for the purpose of creating new industries, strengthen international relationships, exploring our solar system, and increasing the understanding of the earth. Finally, the U.S wanted to improve space based Earth and solar observation capabilities.

The U.S has three interdependent sectors: national security, civil, and commercial. The national security sector is responsible for making space a free and open place to all. NASA (civil sector) shall set exploration destinations to the Moon, Mars, and asteroids by 2025 going beyond those by the mid 2030s. NASA will also continue its work with the International Space Station (ISS) and must look to increase technologies and capabilities by partnering with private and foreign enterprises that they see fit. NASA must develop new launch systems including the next generation rocket. Also, they must maintain a robotic presence in the solar system to conduct scientific investigations. NASA and other government departments will work to monitor weather, terrain, etc on earth from space via satellites. The commercial sector is required to use space practically and follow governmental guidelines. The government will do what it can to stay out of competition with the private sector unless national security requires it to do so. The U.S shall also open U.S space infrastructure to the private sector when they see fit.

With the shift in focus to the commercial sector NASA has taken steps to relinquish some of its influence on the Space Shuttle Program (SSP). Due to budget cuts in this recent national policies and a declining work experience factor, the department has developed an organized method of dividing responsibilities between themselves and the private sector. Table one below outlines which areas NASA will remain in charge of and which areas private companies will begin to oversee.

NASA	Private Company
Asset ownership (to be established)	Accountable
Indemnify private company	Requirements owner
Safety - independent assessment/insight	Safety - direct accountability
Contract/Budget	Program/hardware element management
Technology development	Mission operations
Payload manifest determination	Ground operations/processing
	Payload customer interface
	Sustaining/supportability
	Astronaut - Space Shuttle flight crew
	Asset ownership (to be established)

Table 1- Distribution of Responsibilities

Many private companies in the United States have already begun taking advantage of the general public's interest in space. A company called *Space Adventures* has already sent seven private US citizens to the International Space Station. Although *Space Adventures* uses the Russian-made Soyuz aircraft to shuttle clients to and from the ISS, they recently signed a contract with Boeing agreeing to utilize their CTS-100 spacecraft when its prototype has finished testing and been approved for use.

This aspect of space exploration involves significant capital that has attracted many other private businesses. Companies such as SpaceX, Virgin Galactic, and Orbital Sciences are all working on technologies that will possibly be used by NASA to carry out on future missions. In 2006, SpaceX was awarded $231 million from NASA's Commercial Orbital Transport Services contract to put towards the task of designing a new launch vehicle using modern booster rockets. Their prototype, the Falcon-9 uses nine Merlin rocket engines to deliver over 5 MN (mega-Newtons) of liftoff thrust. In 2008, SpaceX won the Commercial Resupply Services contract that guaranteed at least 12 future cargo-carrying missions after the space shuttle retires, totaling a sum of $1.6 billion. Last June, they received another contract for $492 million to carry satellites to the ISS. In December, they became the first private company to launch a spacecraft into orbit and successfully return it. The financial success of SpaceX indicates that establishing a lunar outpost could prove to be a lucrative endeavor.

GETTING TO THE MOON

INTRODUCTION

The first step in establishing a lunar outpost is being capable of traveling to the moon. In this section we examine methods of travelling to the Moon both safely and efficiently. We will be examining different methods of getting to the Moon including patched conic transfer, Hohmann transfer, Lagrangian point transfer, and slow orbit increasing transfer. We will examine the advantages and disadvantages of each of these transfers, and determine whether or not one is ideal for either human or cargo transport to a lunar base.

HOHMANN TRANSFER ORBITS

The Hohmann transfer orbit is an orbital maneuver using two engine impulses that under standard assumptions move a spacecraft between two coplanar circular orbits.

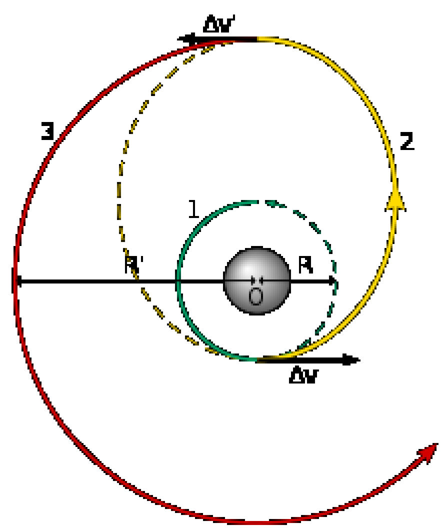


Figure 1 - Example Hohmann Transfer Orbit

Figure 1 above shows a Hohmann transfer orbit to bring a spacecraft from a lower circular orbit into a higher one. It is one half of an elliptic orbit that touches both the lower circular orbit that one wishes to leave and the higher circular orbit that one wishes to reach. The transfer is initiated by firing the spacecraft's engine in order to accelerate it so that it will follow the elliptical orbit; this adds energy to the spacecraft's orbit. When the spacecraft has reached its destination orbit, its orbital speed (and hence its orbital energy) must be increased again in order to change the elliptic orbit to the larger circular one.

FORMULAS

The total energy of the body is the sum of its kinetic energy and potential energy, and this total energy also equals half the potential at the average distance a, (the semi-major axis):

$$E = \tfrac{1}{2}mv^2 - \frac{GMm}{r} = \frac{-GMm}{2a} \quad \text{Equation 1}$$

Equation one can be rearranged into:

$$v^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right) \quad \text{Equation 2}$$

Where v is the speed of an orbiting body, μ is the standard gravitational parameter of the primary body, r is the distance of the orbiting body from the primary focus, and a is the semi-major axis of the body's orbit. Thus, the delta V (or total velocity change) of this transfer is:

$$\Delta v = \sqrt{\frac{\mu}{r_1}}\left(\sqrt{\frac{2r_2}{r_1 + r_2}} - 1\right) \quad \text{Equation 3}$$

And the time of the transfer is:

$$t_H = \tfrac{1}{2}\sqrt{\frac{4\pi^2 a_H^3}{\mu}} = \pi\sqrt{\frac{(r_1 + r_2)^3}{8\mu}} \quad \text{Equation 4}$$

Hohmann transfers guarantee an extremely efficient transfer however Hohmann transfers are absolutely ideal scenarios, and cannot be reasonably performed in our Solar System.

PATCHED CONIC

The Hohmann transfer orbit alone is a poor approximation for interplanetary trajectories because it neglects the planets' own gravity. Planetary gravity dominates the behavior of the spacecraft in the vicinity of a planet and in most cases Hohmann severely overestimates delta-v, and produces highly inaccurate prescriptions for burn timings.

A relatively simple way to get an approximation of delta-v is based on the "Patched Conic Approximation" technique. One must choose the one dominant gravitating body in each region of space through which the trajectory will pass, and to model only that body's effects in that region.

A trajectory from the Earth to Mars, one would begin by considering only the Earth's gravity until the trajectory reaches a distance where the Earth's gravity no longer dominates that of the Sun. The spacecraft would be given escape velocity to send it on its way to interplanetary space. Next, one would consider only the Sun's gravity until the trajectory reaches the neighborhood of Mars. During this stage, the transfer orbit model is appropriate. Finally, only Mars's gravity is considered during the final portion of the trajectory where Mars's gravity dominates the spacecraft's behavior. The spacecraft would approach Mars on a hyperbolic orbit, and a final retrograde burn would slow the spacecraft enough to be captured by Mars.

The size of the spheres of influence vary with radius r_{SOI}:

$$r_{SOI} = a_p\left(\frac{m_p}{m_s}\right)^{\frac{2}{5}}$$

Equation 5

where a_p is the semimajor axis of the planet's orbit relative to the Sun; m_p and m_s are the masses of the planet and Sun, respectively.

This simplification is sufficient to compute rough estimates of fuel requirements, and rough time-of-flight estimates, but it is not generally accurate enough to guide a spacecraft to its destination. For that, numerical methods are required.

The sphere of influence of the Earth is about 925,000 kilometers in radius. The sphere of influence of the Moon is 66,100 kilometers in radius.

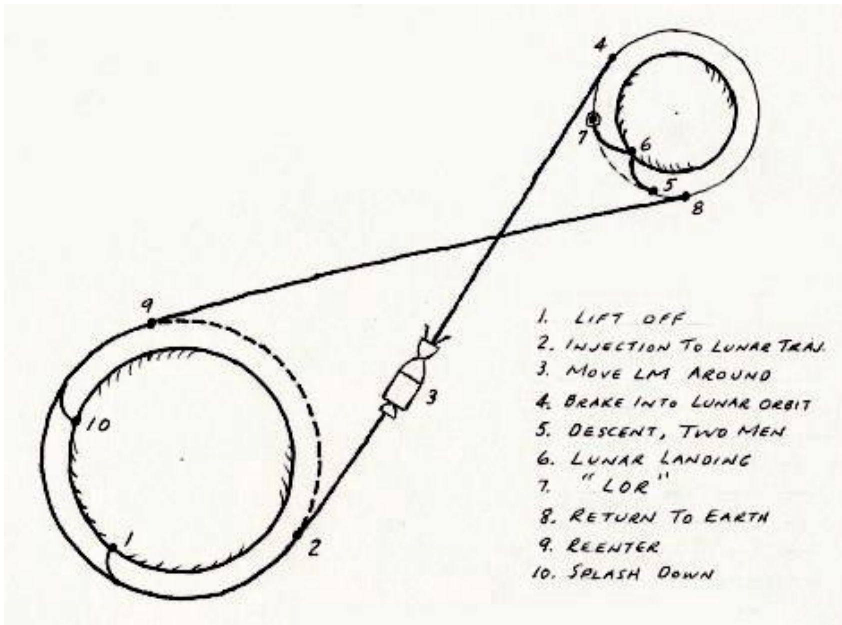


Figure 2 - Patched Conic Transfer used in Apollo Missions

Figure 2 above is a sketch of the lunar transfer and trajectory used for the Apollo missions showing the places of all transfers and delta-v.

Since our only manned missions to the lunar surface were the Apollo missions, we will take a look at the details and cost of the Saturn V rocket.

A Saturn V launched Apollo 11 from Launch Pad 39A, part of the Launch Complex 39 site at the Kennedy Space Center on July 16, 1969 at 13:32:00 UTC [Part 1 of diagram]. It entered orbit 12 minutes later. After one and a half orbits, the S-IVB third-stage engine pushed the spacecraft onto its trajectory toward the Moon with the Trans Lunar Injection burn at 16:22:13 UTC [Part 2]. On July 19 at 17:21:50 UTC, Apollo 11 passed behind the Moon and fired its service propulsion engine to enter lunar orbit [Part 4].

The time taken to make the trip from the Earth to the Moon using a trans-lunar trajectory during the Apollo 11 mission was 3 days, 58 minutes, 37 seconds. To approximate the fuel that the Apollo missions used we need to look at the Saturn V rocket.

S−IC FIRST STAGE

The S-IC stage had a dry weight of about 288,000 pounds (131,000 kg) and fully fueled at launch had a total weight of 5,000,000 pounds (2,300,000 kg). Propellant for this stage was 4,712,000 pounds (2,169,000 kg).

S−II SECOND STAGE

The S-II had a dry weight of about 80,000 pounds (36,000 kg) and fully fueled, weighed 1,060,000 pounds (480,000 kg). Propellant for this stage was 980,000 pounds (444,000 kg).

S−IVB THIRD STAGE

The S-IVB had a dry weight of about 25,000 pounds (11,000 kg) and, fully fueled, weighed about 262,000 pounds (119,000 kg). The propellant for this stage was 237,000 pounds (108,000 kg).

This makes for a total of 5,929,000 pounds (2,721,000 kg) of fuel consumed on the Apollo 11 mission. This also gives us a payload to trans-lunar injection of 100,000 pounds (45,000 kg). From 1964 until 1973, a total of $6.5 billion ($43.99 billion present day) was appropriated for the Saturn V, with the maximum being in 1966 with $1.2 billion ($8.12 billion present day). In 1969, the cost of a Saturn V including launch was US $ 185 million (inflation adjusted US$ 1.11 billion in 2011).

NASA had been developing the Constellation program until the program was cancelled due to a change in space policy. However the vehicles used in Constellation can be considered for our mission of a lunar base. Specifically we can look at the Ares I and Ares V launch vehicles and associated potential costs.

Ares V would have had a maximum payload capacity of about 188 metric tons (414,000 lb) to low earth orbit (LEO), compared to the Space Shuttle's capacity of 24.4 metric tons, and the Saturn V's 118 metric tons. The Ares V would have carried about 71 metric tons (157,000 lb) to the Moon.

Ares I had a payload capability in the 25-metric-ton (28-short-ton; 25-long-ton) class and was comparable to vehicles such as the Delta IV and the Atlas V. The NASA study group that selected what would become the Ares I rated the vehicle as almost twice as safe as an Atlas or Delta IV-derived design. The rocket was to have made use of an aluminum-lithium alloy which is lower in density but similar in strength compared to other aluminum alloys. The new alloy was produced by Alcoa. The upper stage of the Ares I is planned to have 302.2K pounds LOX/LH2 propellant. The mass of propellant required for the lower stage has not been released by NASA.

When President Bush established his new space exploration policy to return humans to the moon, NASA estimated the policy would cost $230 billion (in 2004 dollars) through 2025. This figure includes the Commercial Crew and Cargo program, which is separate from the Constellation program. NASA has estimated that the Constellation program would cost over $97 billion (in 2008 dollars) through 2020, half of which would be for Ares I and Orion. However, unsolved technical and design challenges made it impossible for NASA to provide a credible estimate.

The total estimated cost to develop the Ares I through 2015 rose from $28 billion in 2006 to more than $40 billion in 2009. Originally scheduled for first test flights in 2011, the independent analysis by the Augustine Commission found in late 2009 that due to technical and financial problems Ares I was not likely to have had its first crewed launch until 2017-2019 under the current budget, or late 2016 with an unconstrained budget. The Augustine Commission also stated that Ares I and Orion would have an estimated recurring cost of almost $1 billion per flight. However, later financial analysis showed that the Ares I would have cost $1 billion or more to operate per flight had the Ares I flown just once a year. If the Ares I system were flown multiple times a year the marginal costs could have fallen to as low as $138 million per launch. Figure 3 below shows the key elements of an Ares I and Ares V rocket system.

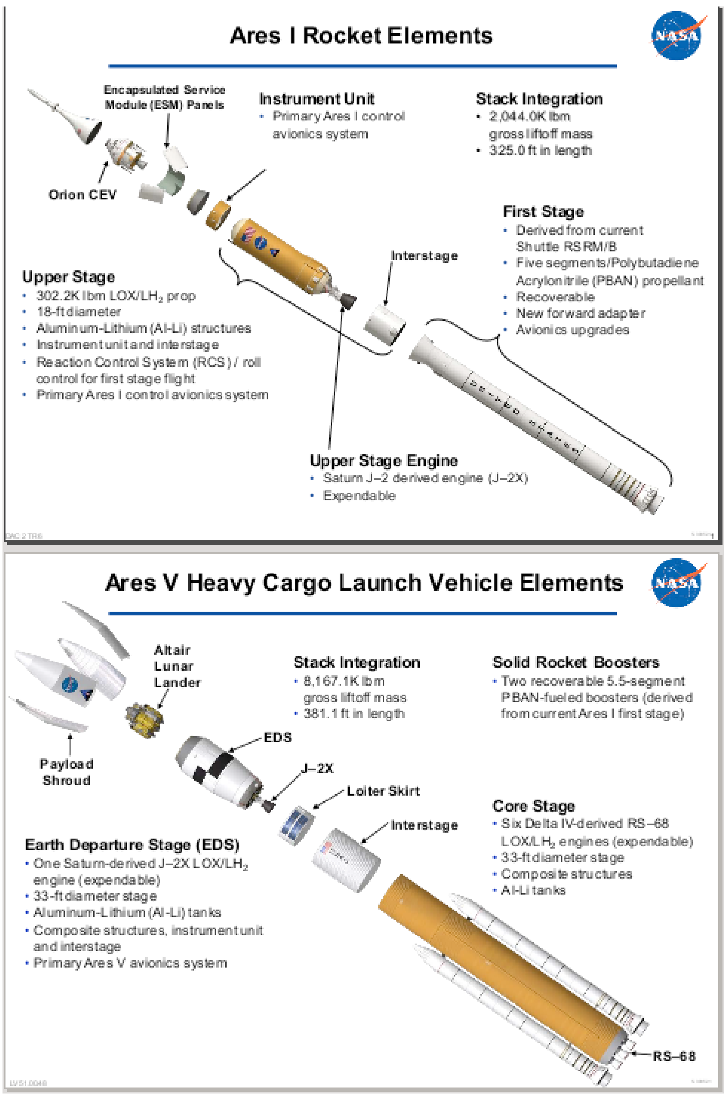


Figure 3 - Ares I and V Rocket Systems

LAGRANGE POINTS

Each two body system has five locations in space called Lagrange points where one body's gravity balances another's. Given two massive bodies in circular orbits around their common center of mass, there are five positions in space where a third body, of comparatively negligible mass, could be placed and then maintain its position relative to the two massive bodies. Three of the five Lagrange points for any two body system in space are co-linear to a line connecting the center of the two bodies. Orbits about these points are unstable and easily breached. The other two points form an equilateral triangle. If an object is at one of the points of this triangle, it will oscillate around the point as long as the mass ratio is less than .0385.

The three collinear Lagrange points were first discovered by Leonhard Euler around 1750. In 1772, the Italian-French mathematician Joseph Louis Lagrange was working on the famous three-body problem and wanted to make it much simpler. He re-formulated the classical Newtonian mechanics to give rise to Lagrangian mechanics. With his new system of calculations, Lagrange's work led him to theorize how a third body of negligible mass would orbit around two larger bodies which were already in a near-circular orbit. In a frame of reference that rotates with the larger bodies, he found five specific fixed points where the third body experiences zero net force as it follows the circular orbit of its host bodies.

The positions of the Lagrange points were initially solved using the Circular Restricted Three Body Problem. The term restricted refers to the condition that the two main masses are much heavier than the third. The full three body problem is chaotic and cannot be solved in closed form.

If M_1 and M_2 are the masses of the large objects and r_1 and r_2 are their positions, then the force on the third smaller mass m at position r is:

$$\vec{F} = -\frac{GM_1 m}{|\vec{r}-\vec{r_1}|^3}(\vec{r}-\vec{r_1}) - \frac{GM_2 m}{|\vec{r}-\vec{r_2}|^3}(\vec{r}-\vec{r_2})\,.$$

Equation 6

Here r_1 and r_2 are functions of time because M_1 and M_2 are rotating about each other. One may proceed to inserting the orbital solution for $r_1(t)$ and $r_2(t)$, obtained by solving the two body problem and looking for solutions to the equation of motion that keep the relative positions of the three bodies fixed:

$$\vec{F}(t) = m\frac{d^2\vec{r}(t)}{dt^2}\,,$$

Equation 7

The easiest way to find these stationary points is to hold the two large masses at fixed positions. Assume the origin to be at the center of mass, and an angular frequency Ω given by Kepler's law:

$$\Omega^2 R^3 = G(M_1 + M_2)\,.$$

Equation 8

Here R is the distance between the two masses. The effective force in a frame rotating with angular velocity Ω is related to the internal force F according to the transformation:

$$\vec{F}_\Omega = \vec{F} - 2m\left(\vec{\Omega} \times \frac{d\vec{r}}{dt}\right) - m\,\vec{\Omega} \times (\vec{\Omega} \times \vec{r})\,.$$

Equation 9

Because we have a rotating frame of reference, we have to correct for the Coriolis force and centrifugal force. The effective force can be derived from the generalized potential:

$$U_\Omega = U - \vec{v} \cdot (\vec{\Omega} \times \vec{r}) + \frac{1}{2}(\vec{\Omega} \times \vec{r}) \cdot (\vec{\Omega} \times \vec{r})$$

Equation 10

and from the generalized gradient:

$$\vec{F}_\Omega = -\nabla_{\vec{r}} U_\Omega + \frac{d}{dt}\left(\nabla_{\vec{v}} U_\Omega\right)\,.$$

Equation 11

The velocity dependent terms in the effective potential do not affect the positions of the equilibrium points. By choosing a set of coordinates originating from the center of mass with the z-axis aligned with the angular velocity,

$$\begin{aligned} \vec{\Omega} &= \Omega\,\hat{k} \\ \vec{r} &= x(t)\,\hat{\imath} + y(t)\,\hat{\jmath} \\ \vec{r}_1 &= -\alpha R\,\hat{\imath} \\ \vec{r}_2 &= \beta R\,\hat{\imath} \end{aligned}$$

Equation 12

To find the equilibrium points, we set velocity equal to 0 and seek solutions for where equation 13 below equals zero.

$$\vec{v} = d\vec{r}/dt$$

Equation 13

$$\begin{aligned} \vec{F}_\Omega \;\; = \;\; & \Omega^2\left(x - \frac{\beta(x+\alpha R)R^3}{((x+\alpha R)^2+y^2)^{3/2}} - \frac{\alpha(x-\beta R)R^3}{((x-\beta R)^2+y^2)^{3/2}}\right)\hat{\imath} \\ & \Omega^2\left(y - \frac{\beta y R^3}{((x+\alpha R)^2+y^2)^{3/2}} - \frac{\alpha y R^3}{((x-\beta R)^2+y^2)^{3/2}}\right)\hat{\jmath} \end{aligned}$$

Equation 14

These equations for the Lagrange point locations assume the Earth as the origin at coordinate (0,0).

$$\alpha = \frac{M_2}{M_1 + M_2}$$

Equation 15

The coordinates for each Lagrange point is shown below in equation 16.

$$\begin{aligned} L1: &\quad \left(R\left[1 - \left(\frac{\alpha}{3}\right)^{1/3}\right], 0\right) \\ L2: &\quad \left(R\left[1 + \left(\frac{\alpha}{3}\right)^{1/3}\right], 0\right) \\ L3: &\quad \left(-R\left[1 + \frac{5}{12}\alpha\right], 0\right)\,. \end{aligned}$$

$$L4: \quad \left(\frac{R}{2}\left(\frac{M_1 - M_2}{M_1 + M_2}\right), \frac{\sqrt{3}}{2}R\right),$$

$$L5: \quad \left(\frac{R}{2}\left(\frac{M_1 - M_2}{M_1 + M_2}\right), -\frac{\sqrt{3}}{2}R\right).$$

Equation 16

Using these equations (derived courtesy of Neil J. Cornish, faculty at Montana University), for the Earth-Moon system α=0.98783and R=384,403 km. The Lagrange points can be solved to be: L1=118,958 km from Earth, L2=649,848 km from Earth and is actually on the opposite side of the Moon from the Earth, L3=542,622 km from Earth on the side away from the moon. L2 and L3 are located where they are due to the centrifugal and coriolis forces that act on the large bodies. L4 and L5 are at a 60-degree angle along the Moon's orbit ahead or behind it and approximately 374,270 km from Earth. According to Martin Lo of the Jet Propulsion Laboratory at California Institute of Technology, the Lunar L1 can be reached from Earth in less than a week and from that point any spot on the surface of the moon can be reached within hours (Lo).

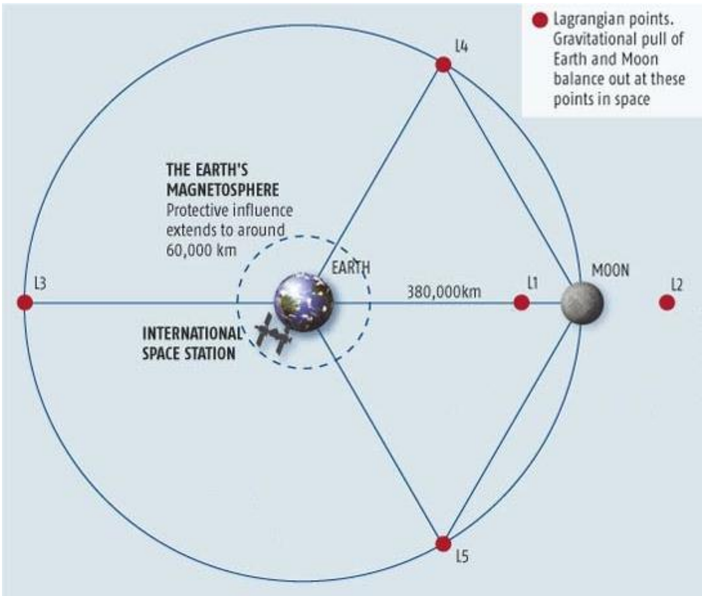


Figure 4 - Lagrangian Points Relative to Earth and the Moon

Henri Poincaré worked on the three-body problem. His crucial observation was that although it is impossible to precisely predict the trajectories of particles near the unstable Lagrange points, you can separate out families of trajectories that behave similarly. These similar trajectories together form the surface of a tube or tunnel. The surface of the tunnel is generated by all the trajectories that asymptotically wind onto the halo orbit without any maneuvers. This tube-like surface is called the stable manifold. Similarly, there is a set of trajectories that asymptotically wind off of the halo orbit without any maneuvers. This tunnel is called the unstable manifold (Lo 6).

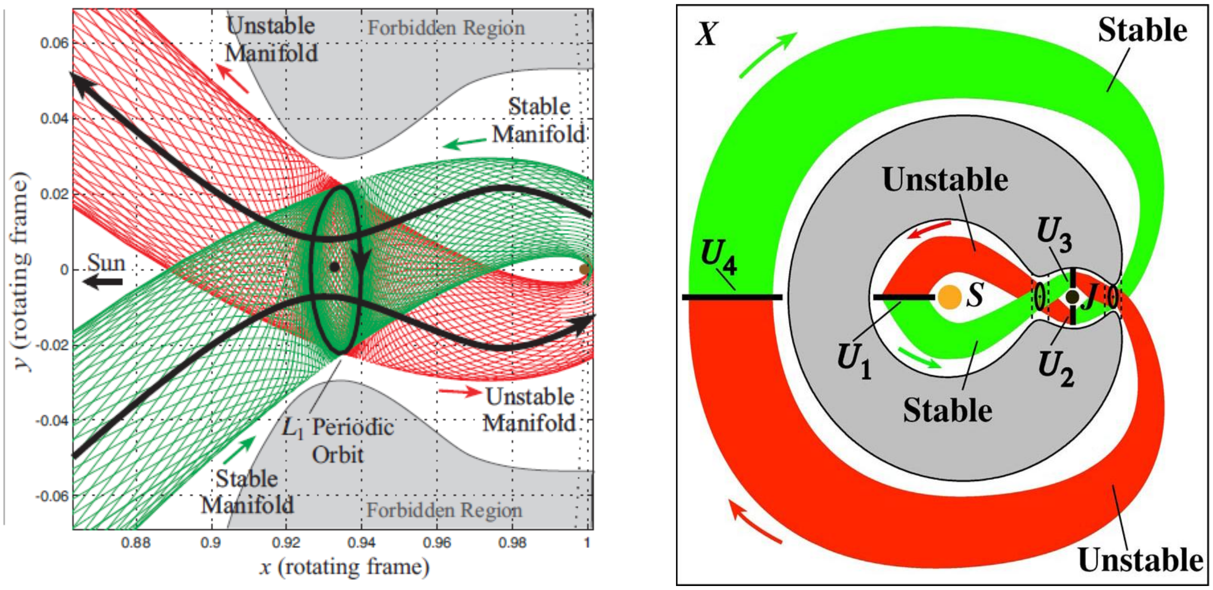


Figure 5 - The Unstable Manifolds within the Lagrange Point

In chaos theory, systems like the LL1 Lagrange point are known as "highly nonlinear dynamical regions". If an object close to LL1 gets nudged, it will drift away. Even a slight alteration to a trajectory passing close to LL1 will take it off into a different direction and lead to a large change in the eventual path of the spacecraft. This is more popularly known as the "Butterfly Effect."

The positive of all this is that a spacecraft swinging past LL1 can easily push itself from one low-energy trajectory onto another that leads to a completely different destination. Therefore very little fuel would need to be used at all if traveling between the Lagrange points. There is some delta V required to get from LL1 to the lunar surface. Regardless of the path to the Moon, all crafts must first get to Low Earth Orbit (LEO) and the delta V needed to reach LEO from the ground is approximately 9.3 km/s. The corresponding delta V required to lift a spacecraft from LEO to the Lunar Lagrange point LL1 is roughly 3.8 km/s. Theoretically you could design an orbit to get from LL1 to lunar orbit using very low or no delta V, and would bring the total delta V needed to reach lunar orbit to 13.1 km/s. Currently there is a delta V required from LL1 to the lunar surface and it brings the entire delta V to about 15.6 km/s. The current method is Patched conic transfer with a delta V of approximately 15.2 km/s. The difference in delta V actually favors the use of Patched conic transfer over the use of the Lagrange points for such a short mission.

HALL THRUSTERS

Another mode of getting to the Moon is through the use of Hall thrusters. A Hall thruster is a type of ion thruster in which the propellant is accelerated by an electric field. The SMART-1 probe used a revolutionary ion engine to propel itself to the moon and only used an incredibly low 82 kg of Xenon propellant to get there. Hall thrusters trap electrons in a magnetic field and then use the electrons to ionize propellant, efficiently accelerate the ions to produce thrust, and neutralize the ions in the plume. The downfall of this method is the travel time to the Moon. It took the SMART-1 probe 1 year, 1 month and 2 weeks to reach its destination on the lunar surface.

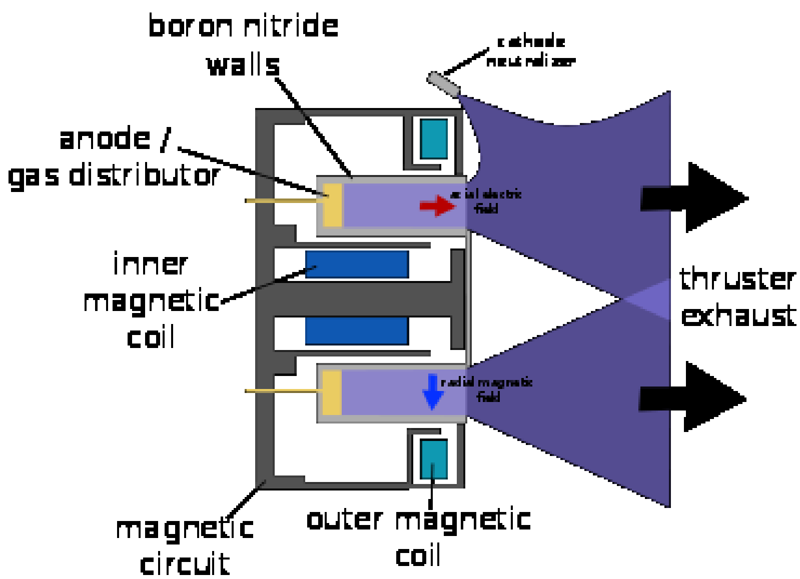


Figure 6 - Hall Thruster Diagram

The technology of Hall Effect Thrusters initially came to be in the 1950's in the Soviet Union and the United States. Due to lack of efficiency, the United States ceased developments around 1970 and focused more on the development of gridded ion propulsion. The Soviet Union however continued to work on this technology and in shared their developments with the western world. This technology was mostly used for station keeping in satellites and was first used successfully outside of Earth's orbit on the European Space Agency lunar mission SMART-1 in 2003.

The principle of the Hall thruster is that it uses an electrostatic potential to accelerate ions up to high speeds. The negative charge is provided by electron plasma at the open end of the thruster. A radial magnetic field is used to trap the electrons, where the combination of the radial magnetic field and axial electric field cause the electrons to drift causing the Hall current. An electric potential is applied between the anode and cathode causing a voltage drop.

The propellant, such as xenon gas is fed through the anode. Xenon propellant is commonly used because of its high molecular weight and low ionization potential. As the neutral xenon atoms disperse into the channel of the thruster, they are ionized by collisions with high energy electrons. The xenon ions typically have a charge of +1 although a small fraction of them are +2.

The xenon ions are then accelerated by the electric field between the anode and the cathode. Upon exiting however, the ions pull an equal number of electrons with them, creating a plume with no net charge.

The radial magnetic field is designed to be strong enough to substantially deflect the low-mass electrons, but not the high-mass ions that have a much larger gyro radius and are hardly impeded. The majority of electrons are thus stuck orbiting in the region of high radial magnetic field near the thruster exit plane, trapped in E×B (axial electric field and radial magnetic field). This orbital rotation of the electrons is a circulating Hall current and it is from this that the Hall thruster gets its name.

Only about 20-30% of the discharge current is an electron current and does not produce thrust. The other 70-80% of the current is in the ions. Because the majority of the electrons are trapped in the Hall current, they have a long residence time inside the thruster and are able to ionize almost all of the xenon propellant, allowing for mass utilizations of 90-99%. The mass utilization efficiency of the thruster is thus around 90%, while the discharge current efficiency is around 70% for a combined thruster efficiency of approximately 63%. Modern Hall thrusters have achieved efficiencies as high as 75% through advanced designs. Compared to chemical rockets the thrust is very small, on the order of 83 mN for a typical thruster operating at 300 V, 1.5 kW. Hall thrusters however, operate at high specific impulses that are typical of electric propulsion. One particular advantage of Hall thrusters, as compared to a gridded ion thruster, is that the generation and acceleration of the ions takes place in quasi-neutral plasma and so there is no Child-Langmuir charge (space charge) saturated current limitation on the thrust density. This allows for much smaller thrusters compared to gridded ion thrusters. Another advantage is that these thrusters can use a wider variety of propellants supplied to the anode, even oxygen, although something easily ionized is needed as the cathode.

COMPARISON

The table 2 shows all calculated delta-v budgets for many different transfers:

From\To	LEO-Ken	LEO-Eq	GEO	EML-1	EML-2	EML-4/5	LLO	Moon	C3
Earth	9.3 - 10								
Low Earth Orbit (LEO-Ken)		4.24	4.33	3.77	3.43	3.97	4.04	5.93	3.22
Low Earth Orbit (LEO-Eq)	4.24		3.90	3.77	3.43	3.99	4.04	5.93	3.22
Geostationary Orbit (GEO)	2.06	1.63		1.38	1.47	1.71	2.05	3.92	1.30
Lagrangian point 1 (EML-1)	0.77	0.77	1.38		0.14	0.33	0.64	2.52	0.14
Lagrangian point 2 (EML-2)	0.33	0.33	1.47	0.14		0.34	0.64	2.52	0.14
Lagrangian point 4/5 (EML-4/5)	0.84	0.98	1.71	0.33	0.34		0.98	2.58	0.43
Low Lunar orbit (LLO)	1.31	1.31	2.05	0.64	0.65	0.98		1.87	1.40
Moon (Moon)	2.74	2.74	3.92	2.52	2.53	2.58	1.87		2.80
Earth Escape velocity (C3)	0.00	0.00	1.30	0.14	0.14	0.43	1.40	2.80	

Table 2 - Comparison of Transfer Types

Table 3 shows several transfers, but also presents the additional propellant mass in the form of a "surcharge" per kilogram placed on the mission to deliver the payload to the given destination. For example, in the first entry, we see that delivery of a kilogram of payload to GEO requires a surcharge of 2.4 kg. Thus, delivery of 1 kg to GEO requires delivery of 3.4 kg first to LEO.

Path	Delta-V (km/sec)	Propellant Mass "Surcharge"
LEO to GEO	4.33	2.44
LEO to L1	3.77	1.87
LEO to Lunar Surface	5.91	5.24
LEO to Mars Escape	3.71	1.81
LEO to GEO to Lunar Surface	8.25	27.84
LEO to GEO to Mars Escape	6.77	8.40
LEO to L1 to Lunar Surface	6.29	6.40
LEO to L1 to Mars Escape	4.26	2.80

Table 3-Tranfers and Their Respective Propellant Mass

The total delta-v is a little bit larger for a LEO to L1 to Lunar transfer (6.29 km/s) and also has a larger propellant mass surcharge (6.40) when compared with the LEO to Lunar transfer (5.91 km/s and 5.24 respectively).

FUTURE CONSIDERATIONS

A single stage to orbit (SSTO) vehicle can obtain orbit by using only a single stage rocket. There has never been a vehicle to accomplish this task from the surface of the Earth. All vehicles that have reached space have done so by either multi-stage rockets or expendable rockets such as the solid rocket boosters for the Space Shuttle. There are a few different theorized approaches to a SSTO vehicle including pure rockets that are launched and land vertically, nuclear-powered vehicles, air-breathing scramjet-powered vehicles that are launched and land horizontally, and even jet-engine-powered vehicles that can fly into orbit and return landing like an airliner, completely intact. A reusable vehicle must be rugged enough to survive multiple round trips into space without adding excessive weight or maintenance. In addition a reusable vehicle must be able to reenter without damage, and land safely. SSTO vehicles would ideally include better reliability than current launch vehicles, lower operating costs, and improved safety. The difficulties with an SSTO vehicle, barring any materials or propulsion technology breakthroughs, is that it is very difficult to design one that would even get close to orbit and anything that would make it would carry a payload that would be for all intents and purposes useless. Tsiolkovsky's rocket equation shows that dead weight will prevent a vehicle from reaching orbit unless the mass ratio (ratio of propellant to structural mass) is very high — between about 10 and 25. However as materials and propulsion technologies continue to develop, a SSTO vehicle might soon become economically viable.

Nuclear propulsion systems have the ability to overcome the Isp limitations of chemical rockets because the source of energy and the propellant are independent of each other. The energy comes from a critical nuclear reactor in which neutrons split fissile isotopes, such as 92-U-235 (Uranium) or 94-Pu-239 (Plutonium), and release energetic fission products, gamma rays, and enough extra neutrons to keep the reactor operating. The energy density of nuclear fuel is enormous. For example, 1 gram of fissile uranium has enough energy to provide approximately one megawatt (MW) of thermal power for a day.3

The heat energy released from the reactor can then be used to heat up a low-molecular weight propellant (such as hydrogen) and then accelerate it through a thermodynamic nozzle in same way that chemical rockets do. This is how nuclear thermal rockets (NTR's) work. There are two main types of NTR's: solid core and gas core. Solid-core NTR's have a solid reactor core with cooling channels through which the propellant is heated up to high temperatures (2500-3000 K). Gas core nuclear rockets (GCNR) can operate at much higher temperatures (5000 - 20000 K), and thus achieve much higher Isp's (up to 6000 s). However the big problem in NTRs is that radioactive fission products will end up in the exhaust. Because of this, NTRs will probably not replace chemical rockets as the primary launch vehicle propellant but they could be utilized for interplanetary travel.

An alternative approach to NTR's is to use the heat from nuclear reactor to generate electrical power through a converter, and then use the electrical power to operate various types of electrical thrusters (ion, hall-type, or magneto-plasma-dynamic (MPD)) that operate on a wide variety of propellants (hydrogen, hydrazine, ammonia, argon, xenon, fullerenes) This is how nuclear-electric propulsion (NEP) systems work.

NASA first researched a nuclear powered engine in the 1960s and the early 70s. The project for this research was called the NERV rocket. This project's goal was to make a nuclear reactor powered propulsion system for a Saturn V rocket. However problems quickly arose from political pressure, environmental concerns, and design flaws. America was still in the throes of a nuclear arms race and cold war coupled with the chance of a possible accident, so nuclear power was strongly lobbied against. Also, the environmental concerns about radioactive waste played a big part in killing the project. The final nail in the coffin was the effectiveness of the NERV rockets in comparison to conventional rockets already in use. The main problem was that the rockets were not able to efficiently convert the energy of the nuclear reactions. This made them only as or less powerful than rockets already used. The project eventually ended in 1972.

The next nuclear propulsion attempt by NASA started in 2003 with the Prometheus Project. This project uses a multipronged approach following the two main lines of research for nuclear powered rocket propulsion. The first approach is Nuclear Thermal Propulsion (NTP) and second Nuclear Electric Propulsion (NEP). While some progress is being made economics stresses are affecting the budget for the project further impeding any significant progress.

So how does each of the present concepts for nuclear propulsion work? The principals are simple but the execution can be complicated. NTP works on the same concept as a hydrogen rocket. The material that makes thrust is heated by a heat source. In this case it is a nuclear reactor. The sheer energy this system can produce when properly managed can exceed that of normal rocket systems.

Unfortunately this type of propulsion is highly inefficient as the temperatures needed to make it truly effective would actually melt any known material now used to make rockets. To prevent this, the engine would have to lose 40% of its efficiency. The other approach is Nuclear Electric Propulsion. This works on the concept of using electrical power to heat the rocket propellant. The main design concept now in use for this type of propulsion is the Radioisotope Thermoelectric Generator. The generator is powered by the decay of radioactive isotopes. The heat generated by the isotopes is captured by thermocouples that convert this heat to the electricity needed to heat rocket propellants. That technology is currently being used by NASA deep space probes like Voyager and Cassini.

One major issue facing nuclear propulsion to be used exclusively in a launch vehicle that wasn't previously mentioned is that the materials just aren't capable yet. The vehicle would need to have sufficient shielding however the shielding that would need to be added would be much too heavy. The shielding will drag the mass ratio down to a point where the vehicle would struggle to achieve orbit or carry very little payload.

Our Findings on Transportation

We have determined that currently the most efficient way to get both people and cargo to the Moon would be using the patch conic transfer used on the Apollo missions. However, if travel using the slower method employed by the Hall Ion thrusters on the SMART-1 Probe were to be successfully implemented on a larger scale, this method would be the smartest for cargo due to the very low amount of propulsion needed for the transfer. Conversely, if we were to place a space station (which many researchers believe is a sensible "next step") at the LL1 point, then that method would likely become the best way for Earth-Moon travel since a vehicle could temporarily dock there if necessary, and it gives the vehicle the option of not being restricted to a flight window or a landing zone as you could transfer to any part of the surface. For longer distances, let's say a transfer to Mars, using Lagrangian point travel is the smartest choice because of the delta-v savings.

THE INITIAL LOCATION

To establish a self-sustaining lunar outpost energy, water, and shelter would need to be acquired. The means of these resources need to be renewable or exist in immense quantities in order to be considered useful by the lunar outpost. The information that is analyzed regarding the location and means of water and energy resources is based upon experimental data acquired in several missions from NASA and other organizations. Since the data is experimental an initial probing mission would be needed in order to confirm the data established by the Clementine, the Chandryaan-1, Kaguya, and SELENE missions. Specifically, water's location in lunar craters would need to be pinpointed more precisely.

The moon's spin axis is less than 2 degrees relative to its orbital plan. Due to this angle the inside of many low points never see light making those regions very cold and permanently dark. However, certain peaks stay illuminated nearly constantly which gives them little temperature variation over time. This variation is estimated to be between -50 and 10 degrees Celsius. This temperature variation is important because a change in temperature can cause materials to change their dimensions. The contraction and expansion of materials due to a change in temperature cause thermal displacement. Thermal displacement will cause a thermal stress in equipment leading to an eventual failure over time. Therefore the locations with the smallest variations in temperature will allow materials to be used for longer durations saving money and time on fewer repairs. In addition to maintaining favorable temperatures the near constant illumination is ideal for collecting solar energy and the permanent darkness is necessary for the possibility of water ice being present. These regions exist on both poles of the moon and therefore both need to be seriously considered as possible starting locations.

The area around the moon's North Pole consists of three craters (Peary, Hermite, and Rozhdestvensky) with highlands in between. Along the northern rim of the Peary Crater is a location that sees nearly continuous sunlight during a lunar summer day. The discovery of this location was a result of the Clementine mission in 1994. Clementine was a satellite equipped with advanced cameras created by NASA to gain a better understanding of the moons surface. Clementine's arsenal included an infrared camera, UV visible camera, near infrared, and long wavelength infrared camera. Using a laser ranging system 70,000 points of the lunar surface were received, which was only about 20% of the data sent, and completely mapped the moon in 11 spectral bands.

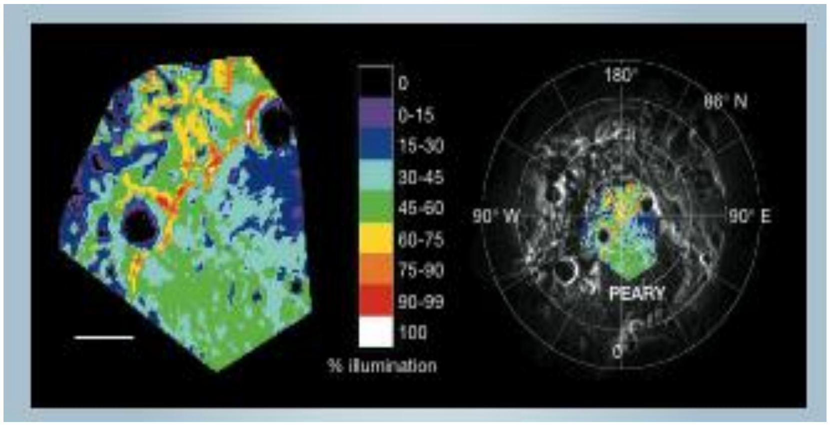


Figure 7- Percent Illumination for the Moon's North Pole

Figure 7 above is a qualitative illumination map of the Moon's North Pole during a lunar summer day where a lunar day measures about a month in earth days. North of Peary lies a crater where there is strong evidence supporting the existence of water in this location. Providing the information about the water on the moon is the radar NASA flew aboard India's Chandrayaan-1 Spacecraft. NASA used lightweight synthetic aperture radar (SAR) that found an estimated 1.3 trillion pounds of ice. This device uses polarization properties of reflected radio waves to characterize surface properties. SAR initially sends out pulses of left circular polarized radio waves. Planetary surfaces reverse these waves to right circular polarized waves. The circular polarization ratio (CPR) is the ratio between the received power versus transmitted power. This ratio can identify rough fresh surfaces and ice by coming back higher than the norm. When the CPR is the same on the outside of the rim as it is on the inside, it is a strong indication that the CPR is showing a rough fresh crater. However, when the CPR on the inside is higher than the outside this indicates that roughness is not the cause of the data but instead by something that is prohibiting the reading within the crater. It is interpreted that higher CPR inside the crater is consistent with water ice present.

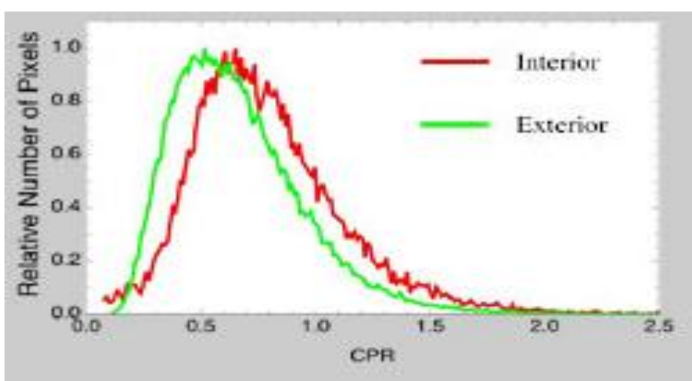


Figure 8 - CPR Data for a Rough Fresh Crater

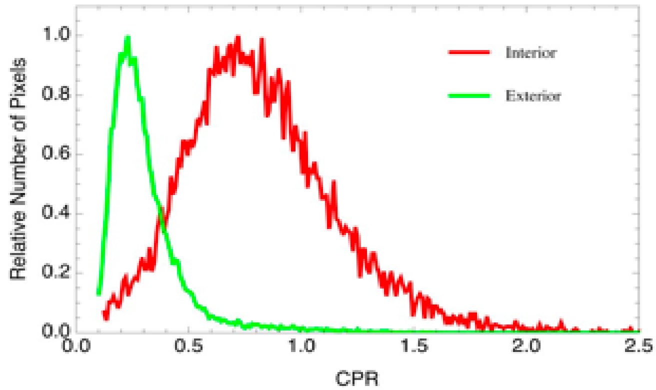


Figure 9 - CPR Data for a Water Ice Crater

Figures 8 and 9 above show the CPR data for a rough fresh crater and CPR data for a water ice crater. Figure 8 is from a crater located at coordinates 81.4˚ north and 22˚ east. Figure 9 is located on the floor of Rozhdestvensky crater at coordinates 84.3˚ north and 157˚ west.

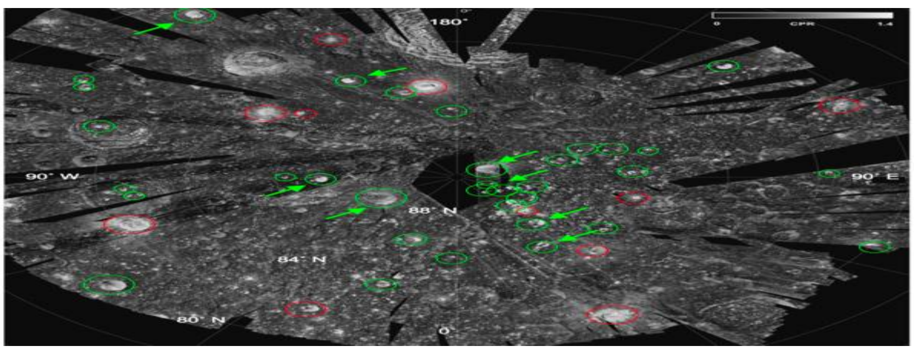


Figure 10 - North Pole CPR results

Figure 10 above shows the CPR results of the north pole of the moon. The green indicates high CPR inside the crater but not outside; potential water ice present. The red circles indicate the same CPR inside the crater and out; rough fresh craters. This image shows that there is an abundance of potential water ice craters on the North Pole. Specifically there is cluster towards the center in the bottom right quadrant of the figure that has a pocket of useable craters. This cluster is in very close vicinity with the Peary Crater, which is a location of high illumination, making this vicinity very resourceful for a lunar outpost.

Another experiment examining the illumination conditions on the moon took place using Kaguya altimeter derived topography. This experiment was conducted in several steps. The first step was comparing the altimeter-derived topography with the results from the Clementine mission. This was done so the Clementine mission could serve as the control for the results of the altimeter. As mentioned above the Clementine mission produced topographical maps for the entire moon. Next, the permanently shadowed regions that do not receive any sun or earth illumination were calculated. Thirdly, illumination profiles were created for the entire year which included accounting for seasonal variations between summer and winter. Due to software restrictions detailed illumination maps were done within 4 ° latitude of the South Pole.

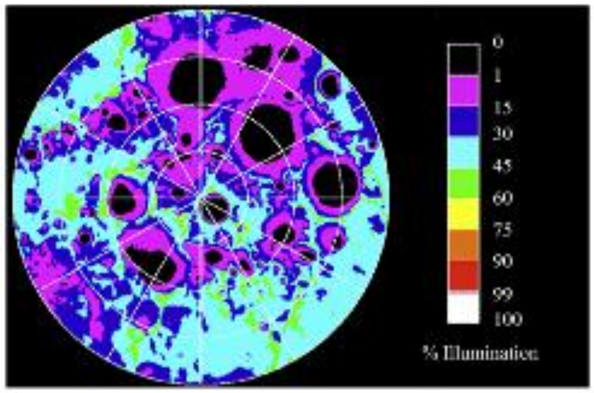


Figure 11 - Percent Illumination for the Moon's South Pole

Figure 11 above is a quantitative illumination map showing a percentage of time that a point on the surface is illuminated for in the year 2020. This map yielded several points on the South Pole that will receive the most illumination throughout the year. The first point lies 89.68°S and 166°W(A) which lies on the Shackleton crater, another point is at 89.44°S and 141.8°W(B) which lies on a ridge close to the Shackleton crater. Another point is near the De Gerlanche crater at 88.71°S and 68.7°W(C) and the final point is also on the Shackleton crater at 99.79°S and 124.5°E (D).

	Point A (89.68°S 166.0°W)	Point B (89.44°S 141.8°W)	Point C (88.71°S 68.7°W)	Point D (88.79°S 124.5°E)	Point M1 (86.04°S 2.7°E)	Point M2 (86.00°S 2.9°W)
Day 1	98	100	98	100	95	90
Day 2	97	100	98	100	92	83
Day 3	97	95	97	100	88	83
Day 4	92	90	86	93	69	75
Day 5	73	64	71	80	64	66
Day 6	51	56	66	63	54	58
Day 7	44	56	64	58	54	58
2020 Mean	81	82	85	86	74	74

Table 4- Percent illumination throughout the year on the Moon's South Pole

Table 4 above shows seasonal variations in illumination conditions for the points identified by the Kaguya to contain the most light in the year 2020. Day 1 represents a mid-summer day and day 7 represents a mid-winter day. A lunar day is about 28 days long 7 lunar days would equal 196 earth days. Due to seasonal symmetry only one half of the year needed to be calculated. Pictures taken by the Advanced Moon micro-Imager Experiment (AMIE) on board the ESA SMART-1 reveal spots of which are nearly continuously illuminated as well.

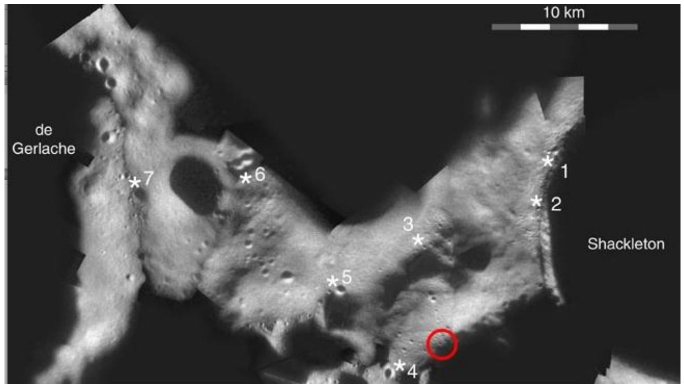


Figure 12 - A Nearly Continuously Illuminated spot on the South Pole

Figure 12 above denotes a spot circled in red between the de Gerlache and Shackleton craters that had been reported by the European Planetary Science Congress in 2008 to be nearly continuously luminous. Three separate experiments (Clementine, Kaguya, SMART-1) yielded very similar results showing us that the current information gathered about illumination on the moons South Pole is reliable. To the North is the Cabeus crater where NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) discovered water ice in craters by kicking up debris and analyzing it in a spectrometer. More specifically the LCROSS reports through neutron scattering that concentrations of hydrogen at latitudes within 20˚ of the poles. Within the Shackleton Crater there has been radar results consistent with volumetric scattering by water ice. This allows scientist to believe that the water is relatively pure at about 90% and is 1 to 2 meters thick. The maximum total water vapor noticed in the plume was 155+/- 12 kilograms. Comparing this water mass to the estimated regolith mass of the impact site the water is estimated to be about 5.6% by mass.

A location of interest on the near side of the moon is a recently discovered lava tube in the rille of the Marius hills region. Its exact location on the near side is roughly 14.2 ˚ north of the equator and 57 ˚ west of the vertical centerline. The Lava tube is 65 meters in diameter and the depth is 80 to 88 meters deep. The location of the hole has no obvious underlying faults and is covered by a think lava sheet that may help protect it from collapse. Scientists unsuccessfully searched for other skylights similar to the one above along other rilles nearby indicated that skylights on the moon are rare. This location would need to be explored further but its underground location protects from radiation and its theorized structural stability could make the location useful for future projects once the initial location and infrastructure has been established.

The north pole, South Pole, and near side location all offer resources that would be necessary for survival on the lunar surface. However the South Pole and North Pole offer better potential for an abundance of necessary resources therefore both should be considered for an initial lunar outpost. The South Pole seems to be the most logical location to place the initial lunar outpost because it offers several locations near one another that receive a significant amount of light year round. Having several locations with high percentages of illumination would allow the initial location to have a couple of solar farms as well as a separate location for a shelter with a favorable mean temperature for material longevity. There is also potential water ice in several of the nearby craters. The South Pole information also has the benefit of being more thorough than the North Pole information because its illumination data was acquired through several experiments.

Once the energy arriving to the moon is established there needs to be a way to collect it. One method to collect solar power on the moon is the use of photovoltaic cells. Photovoltaic is the direct conversion of light into energy through a property of certain materials known as the photoelectric effect. The photoelectric effect is the absorption of photons of light that leads to the release of electrons and causes an electric current that can be harnessed for electricity. The photovoltaic cell is made up of semi-conductors which are thin wafers treated to form an electric field with a positive and negative side. When light hits the semi-conductor electrons are knocked loosed from the atoms of the material. Conductors are used with semi-conductors and an electrical current will form that can be harnessed into energy. The current produced depends on how much light strikes the system that infers that the two most important factors are surface area and intensity of light. Only light strong enough to overcome the band gap of the material can be used and the weaker energy passes through and is not used. The band gap is an amount of energy required for electrons to be knocked loose. Energies too low cannot be used and are wasted. In order to make the most efficient cell possible semi-conductors are stacked because they can convert more of the energy spectrum of light. Gallium arsenide (GaAs), amorphous silicon (a-Si), and copper indium diselenide (CulnSe2) are modern materials being used in photovoltaic cells as semi-conductors. GalnP/GalnAs/Ge triple-junction colar cells are widely used to powering satellites in space and therefore would be suitable to be used on the moon because of the similar conditions they would encounter. Efficiencies have been achieved at about 30.5 % and 37% when the light is concentrated.

After discovering the existence of ice astronauts have begun considering the best ways to harvest the substance. Scientists believe that the water was created by the sun's solar wind (carrying protons and consequently H^+ atoms) crashing into the unprotected Moon's surface at high velocities and separating the O_2 molecules on the surface. The hydrogen and oxygen combine to form an ice dust that builds up in these deep craters. Lunar water could be used to provide oxygen and drinking water to a Moon base using a life-support system similar to that on the space station (the ECLSS). The water could also be turned into rocket fuel that utilizes the burning of oxygen and hydrogen gas as its main propellant. To harvest this water, scientists have simulated lunar soil in vacuum and used microwaves to heat it up. At only -50ºC the water vaporized (due to presence of the vacuum) and was able to be collected using condensation.

Once an environment can be sustained future projects can begin to take shape. Things such as mining helium 3, collecting solar power to beam to earth, creating an observatory, and creating lab space on the moon are all potential revenue generating avenues.

Life Supporting Technologies

Living in space for an extended period of time requires consideration of the necessities for survival. A human being needs sufficient water, food and shelter – three things that can be hard to come by in such a hostile environment. The International Space Station has found ways to maximize efficiency in these areas without losing the quality of life that we're used to. This technology could be used in the maintenance of a lunar base which would need to support life much like the ISS does.

Water & Waste Management

In order for astronauts to live in space for an extended period of time, a system must be implemented that recycles their waste while also supplying them with clean water for bathing and drinking. The Environmental Control and Life Support System (ECLSS) on board the International Space Station executes these tasks using some advanced filtering and recycling methods.

The ISS currently uses a system from the Marshall Space Flight Center's Environmental Control and Life Support System (ECLSS) to provide the astronauts with a clean and renewable form of water. The Water Restoration System (WRS) collects waste water molecules from the station's fuel cells, the astronaut's sweat and urine, even the air humidity, and regenerates up to 40,000 lbs. of water a year. Even with this type of production astronauts must limit their water wastage by using soaked clothes to "shower" with water-less soaps and shampoos. Although the source of the recycled water may seem a bit odd, the water produced from the WRS is cleaner than most tap water found in the United States. This new technology saves Earth from making as many expensive cargo missions to the station; 1 lb. of water costs about $100,000 to deliver. The station still requires minimal supply trips because the system is not 100% efficient and some water is lost through air locks and other various drains. Scientists believe that if a system can be developed to operate at 95% or greater efficiency then the food supplies would provide enough moisture to eliminate the need for water deliveries.

To begin, four large water tanks are pressurized using the excess N_2 gas from the Pressure Control System mentioned in last week's report. The pressure inside these tanks is usually between 30.2 to 31.7 psia allowing the water to be pumped throughout the station without backing up or freezing. This water is originally supplied from the station's fuel cells, the Service Module Air Conditioning System, and the waste-recycling process. A filtration system has been adapted to provide the astronauts with clean water; first, extra H_2 is removed using palladium tubes which attract and collect the molecules as water is run past them. Since water is produced at a faster rate than it is consumed, a water strategy must be developed to maintain adequate levels in the tanks while saving energy on its production. To sustain five astronauts for four days (1 person needs about 6 lbs. of water per day) requires about 128 lbs. of water (the approximate capacity of one tank). A built-in quantity sensor automatically checks the water levels and when they fall below a predetermined value (usually around 60%), the tank refills. A schematic of one tank's operation is shown below in Figure 13.

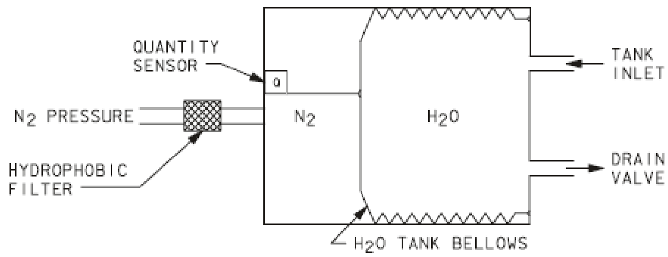


Figure 13 - Water Tank Schematic

This system efficiently provides astronauts with a clean water supply for drinking and bathing, the only problem that remains is what to do with their waste. A separate waste tank is used to hold the astronaut's urine, sweat and breadth condensate collected from multiple locations on the base. On previous missions, astronauts have consumed an average of 6.2 lbs. of water per day so recycling this waste is very important to saving supplies.

The waste water is first passed through two filters to remove dust particles and debris then heated where the clean condensation is collected. This condensate is then passed through a multi-bed filtration system and a catalytic oxidation reactor to remove microscopic bacteria and viruses that still exist in the water. Which holding tank the water is to be sent to depends on what the water is going to be used for: drinking/cooking, hygiene or experimentation. Water that's going to be consumed or used in experiments is constantly monitored and tested for pH levels, ammonia traces, conductivity, microbial concentration, color, odor, turbidity and molecular metal accumulation. The hygiene water is cleaned in a similar manner with less stress on microscopic particle removal. This recycled water is gradually worked back into the main water supply to maintain full-circle system operation. This process makes it possible to move some human elements out of the waste category and into the recyclable materials class. This is very important to sustaining a lunar outpost because managing space and waste disposal would be a large task in itself and anything that can be reused or recycled would reduce the need for delivery or space dumping. The complete waste recovery system is shown in figure 14 below.

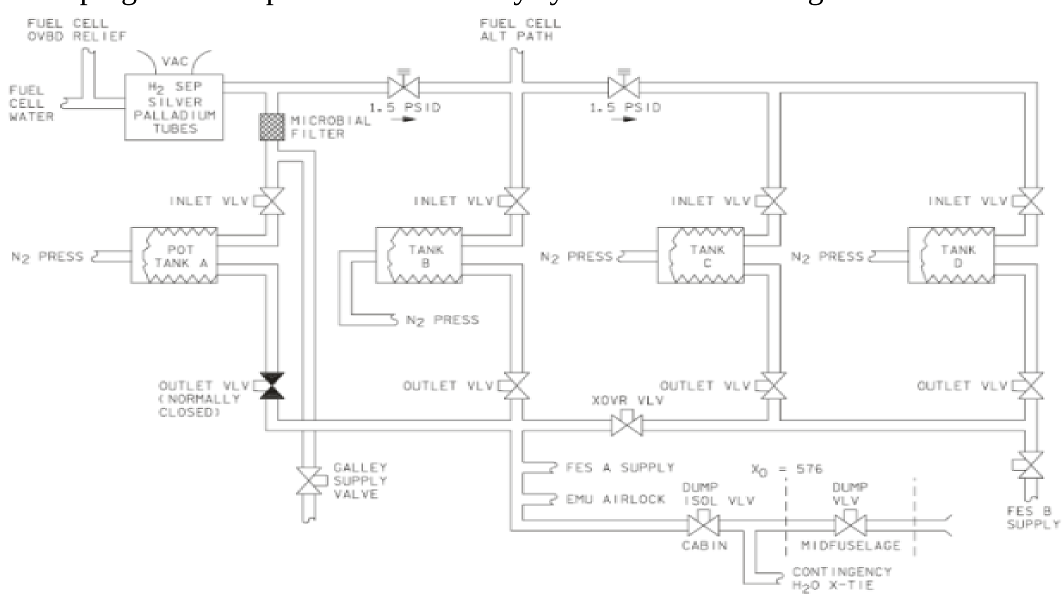


Figure 14 - Waste Recovery System

FOOD

Food in space is sent up in bulk on the aforementioned cargo missions. Astronauts choose meals that suit their tastes and have council from a personal dietician who makes sure they are getting enough nutrients to sustain themselves. Each person is given a weekly repeating menu which includes three meals per day and snacks. Velcro space trays hold food in place while an oven or a rehydrator is used to prepared food that require them. Space food quality has significantly improved in recent years and astronauts can enjoy comfort foods like spaghetti or minestrone soup that tastes almost identical to how it would on Earth. The development of space food that mimics that on Earth is very important to the construction of a lunar base. The only requirement for this food is proper packaging and the capability to prepare it correctly. With ample food and water the only thing left for human survival in space is an acceptable air supply system.

AIR SUPPLY & CABIN PRESSURIZATION

To support human life on a lunar base, the air quality and interior cabin pressure would need to be kept similar to that on Earth. The ECLSS would be the ideal choice for providing and maintaining a life-friendly atmosphere. The oxygen for the system is created through electrolysis of the crew's recycled and filtered waste water. ECLSS electrolysis is a process that uses electricity from the solar panel's fuel cells to split the water molecules into separate hydrogen (H2) and (O2) molecules. The hydrogen is released into space as waste while the oxygen is passed through the O_2 portion of the pressure control system. The equation for electrolysis of water is shown below:

$$2\ H_2O + \text{electricity} \rightarrow 2\ H_2 + O_2$$

After the process is completed, the hydrogen molecules are released into space as waste. The Marshall Center is currently working on a process that takes this hydrogen and combines it with the CO_2 we exhale to produce methane and water. Using this method, the water could be repeated in the electrolysis procedure creating a self-feeding cycle. The extra methane would then become the expelled waste product however; they are looking into ways to use this methane as the thrust booster which keeps the ISS in Earth's orbit.

Air purification is achieved using a material called zeolite to filter out the CO_2 and charcoal to filter out other impurities such as ammonia, methane, carbon monoxide and nitrogen. Researchers must also consider the chemicals released during certain science experiments and figure out how they can be filtered. One proposal is to have each module of the space station responsible for its air supply filtration. This way, if any contamination was to occur, the astronauts could seal the module off and find a way to decontaminate the air. With future installments and upgrades coming to the ECLSS, this system looks like it could provide a lunar base with suitable air quality for humans to live in.

To achieve a suitable cabin pressure, the ECLSS uses a Pressure Control System (PCS) that pumps oxygen (O_2) and nitrogen (N_2) into the compartments. As on Earth, the cabin is pressurized to 14.7 ± 0.2 psia with pressure release valves placed in each compartment to prevent against over and under-pressurization. The PCS also uses N_2 to pressurizer the water supply and

O_2 to fill astronaut's breathing tanks. The composition of the air is kept at about 20% O_2 to 80% N_2 which is approximately what is found at sea level. This allows the crew members to inhale air that is somewhat familiar to the body and does not require adjustment to process.

This system stores the O_2 at high pressures and disperses it through a series of latching solenoid valves and Freon loops to depressurize and cool the gas. Finally, the oxygen is passed through an O_2 flow restrictor that only lets about 23.9 ± 1 lb/hour escape into the cabin. This restrictor maintains the concentration of O_2 in the air making sure that the process never releases too much or too little gas. The N_2 System of the PCS uses nitrogen from at least 8 supply tanks located in a cargo bar area which store the gas at 3300 psia. The system passes N_2 through similar regulator inlet valves which step down the pressure to 200 ± 15 psig. Since the process runs on gas pressure alone, there are constant N_2 regulator relief valves placed along the pipes which release the N_2 into space if the pressure exceeds 275 psig. When the pressure does drop below 14.7 psia, an O_2/N_2 manifold valve controls which gas should be released into the cabin so as to maintain the 20/80 distribution.

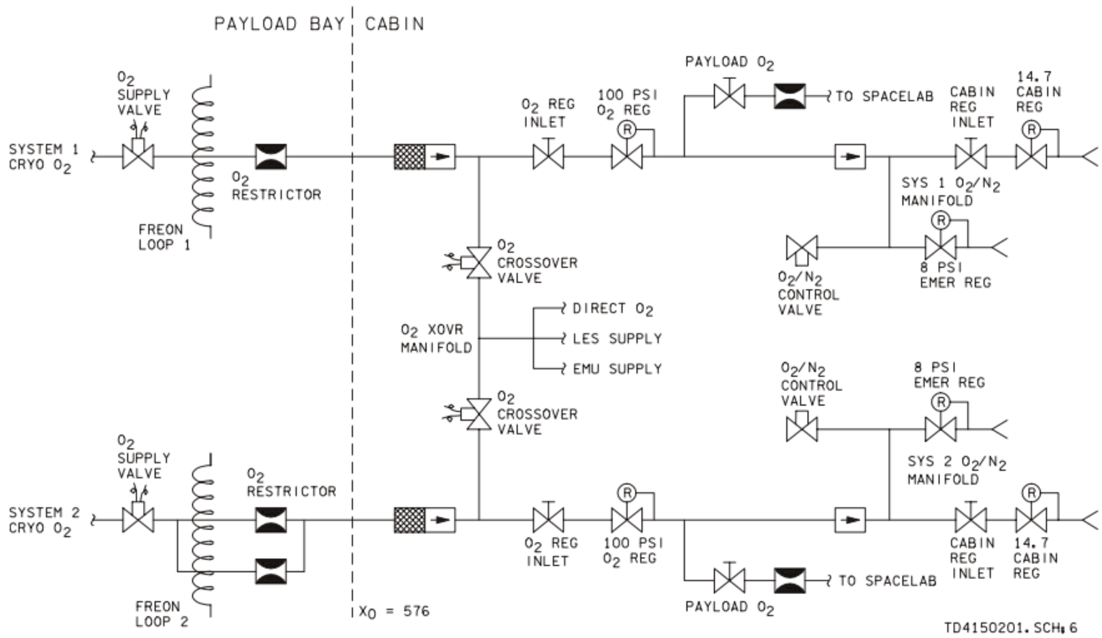


Figure 15 - O_2 Supply System

Along the interior walls of the cabins are Oxygen/Nitrogen Control Valves that automatically manage the amount of O_2 in the air supply. The valves analyze the partial-pressure of oxygen (PPO_2) in the atmosphere to determine which gas needs to be released to re-stabilize the compartment.

$PPO_2 < 2.95$ psia; Valve closed, Oxygen flows in

$PPO_2 < 3.45$ psia; Valve open, Nitrogen flows in

In addition to these O_2/N_2 control valves the ECLSS, the ISS uses pressures relief valves which crack open at 15.5 psid and don't re-seal until the pressure has returned below this value. The complete supply and pressurization system for one cabin of the station is shown below in figure 16.

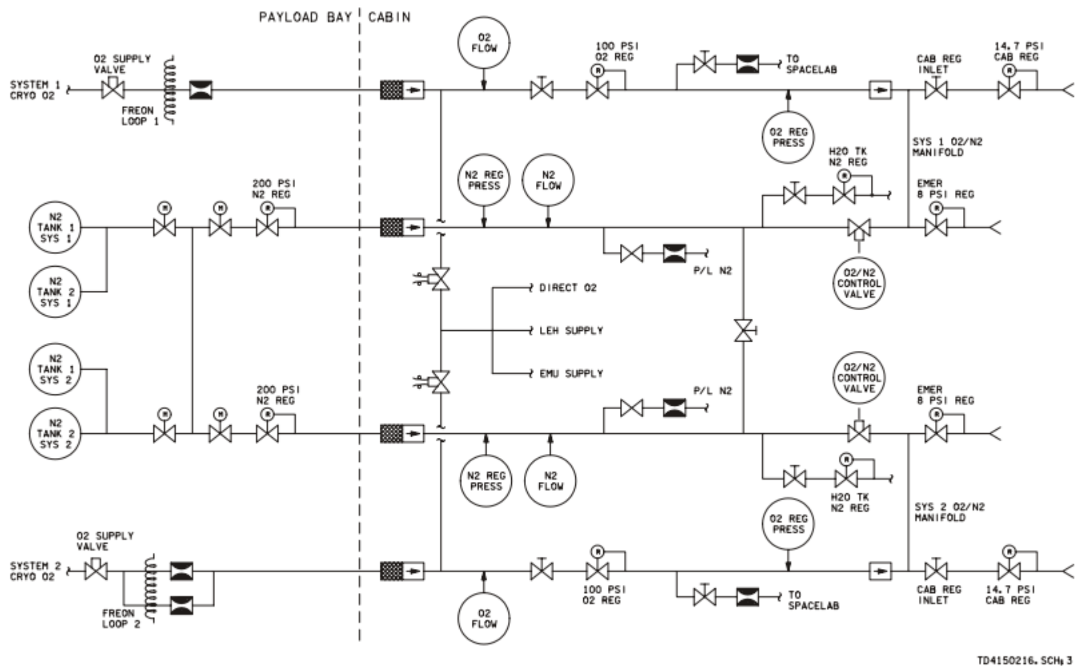


Figure 16 - Complete Air Pressurization System for One Compartment

With upgrades and installments that will improve efficiency currently being tested, the O_2 and Pressure Control systems of the ECLSS appear to be a very feasible and promising unit through which we can provide a lunar base with a suitable interior atmosphere for astronauts to live in.

To achieve success on the moon humans are going to need a safe and reliable source of the things that are essential to life. These essentials include air, water, food, and shelter. In order to keep the costs of a lunar outpost down materials need to be reliable. In order to ensure its longevity, safety and recycling needs to be efficient so the outpost can be as self-sufficient as possible.

LONG TERM GOALS

Once an initial site was established a lunar outpost could do several things to be useful to humanity and produce revenue. These include gathering fuel for nuclear fusion in helium-3, the collection of solar power to beam to earth using wireless power transmission, creating an observatory to look out for near earth objects, uncover parts of solar system history through examination of the moon, as well as other uses. These ideas will be expanded below.

HELIUM-3

Using helium-3 in nuclear fusion is a growing idea among the scientific community. Helium-3 is gaining popularity because it is extremely potent, produces no pollution, and under the current method creates very low amounts of radioactive waste. Helium-3 is found within the sun and travels in the solar wind to the surrounding areas. The earth's atmosphere and magnetic fields protect it from the solar winds keeping helium-3 form reaching the surface making it available in scarce amounts of on earth therefore none is available for commercial use. The moon essentially has no atmosphere. Due to solar winds and meteorite bombardment helium three is embedded within the powdery regolith of the moon. Soil samples of the moon collected during Apollo missions were confirmed to have helium-3 in 1985 at lab at the University of Wisconsin.

Nuclear fusion is combining two small nuclei to make a larger one. To better visualize the process the formation of a deuteron will be examined. A proton and neutron will combine to form a deuteron. The proton is the nucleus of a hydrogen atom and a deuteron is the nucleus of heavy hydrogen atom (also known as an isotope where the number of protons is the same but the number of neutrons is different). When a deuteron is formed its mass is less than the mass of the two nuclei. So when a deuteron is formed it is .00239 amu (1.66x10^-27 KG) less than the mass of a proton and neutron combined. The loss of mass results in energy. E=mc^2 shows the relation between mass and energy where the mass of the body is measured in its energy content.

The following will go over three nuclear reactions that all use deuterium. Deuterium is a very common element and can be acquired from seawater.

Example 1 - deuterium/deuterium reaction

$$D + D \rightarrow n + Helium\text{-}3 \qquad \text{Equation 17}$$

Equation 22 shows Deuterium (D) combining with deuterium (D) to form a free neutron and helium three.

$$D + D \rightarrow tritium + a\ proton \qquad \text{Equation 18}$$

Equation 23 shows Deuterium (D) combining with deuterium to form tritium (an isotope of hydrogen) and proton.

Besides from having two possible reactions deuterium - deuterium reactions produce a tremendous amount of free neutrons.

Example 2 – Deuterium/tritium reaction

$$D + T \rightarrow n + Helium\text{-}4 \qquad \text{Equation 19}$$

Equation 24 shows deuterium (D) combine with tritium (T) to form a free neutron and helium four.

However, tritium is not found naturally on earth and has to be formed in a lab. Tritium has to be man-made and is formed by combining a free neutron with Lithium 6(an isotope of lithium).

Example 3- Deuterium/Helium Three reaction

$$D + Helium\text{-}3 \rightarrow Helium\text{-}4 + proton \qquad \text{Equation 20}$$

Equation 25 depicts deuterium (D) combining with helium-3 to form a proton (hydrogen nucleus) and helium-4.

Example 3 produces no high-energy neutrons and very little radioactive waste. The energy it produces can also be easily manipulated with electricity or magnetic fields making the reactions more energy efficient (positively charged products).

Each of the three examples above has positive and negative aspects. Choosing a nuclear reactant requires several aspects to be taken into account

Choosing a Nuclear Reactant

There are several characteristics of nuclear reactions that need to be analyzed and weighed when choosing a fuel for fusion. These characteristics include but are not limited to the Lawson Criterion/ triple product, relative power density, and the amount of neutrons produced.

Conditions for nuclear fusion require a very high temperature to enable the particles to overcome the electric repulsion to get close enough for the nuclear strong force to take over. The strong force is the force that holds a nucleus together. This temperature needs to be maintained for a sufficient confinement time and with a sufficient ion density in order to obtain a net yield gain from a fusion reaction. Simply the Lawson Criterion can be viewed as overall conditions which must be met for a yield of more energy than is required to heat the plasma this is done by finding the product of confinement time (τ) and ion density (n). Confinement time is the time the plasma is maintained at a temperature above the critical ignition temperature. The critical ignition temperature is the temperature required to overcome coulomb barrier while taking into account tunneling probability. Tunneling probability is the chance after collision between a proton and a proton that one will find itself on the other side of the coulomb barrier and in the well of the strong force. Ion density needs to be maintained to make the probability of collision high enough to achieve net yield energy from the reaction. Currently the triple product is gaining more merit amongst the scientific community it accounts for the Lawson Criterion but in addition accounts for plasma temperature (T).

Important fusion reactions and the particle energy they produce are in the table below. Particle energies listed in "( )" are calculated relativistically. Relativistic energy is the Einstein relationship for energy denoted as E=mc^2. This term includes both kinetic and rest mass energy for a particle. Rest mass energy is the amount of energy in the mass of an electron when it is not in motion. Energies that are not in parenthesis represent the total energy released. (All energies are listed in mega electron volts MeV).

Reaction	Products
Deuterium (D) + Tritium (T)	Helium - 4 (3.561) + neutron (14.029)
D + Helium – 3 (3He)	Helium – 4 (3.712) + protium (14.641)
3He + 3He	Helium – 4 + 2 protium + 12.860

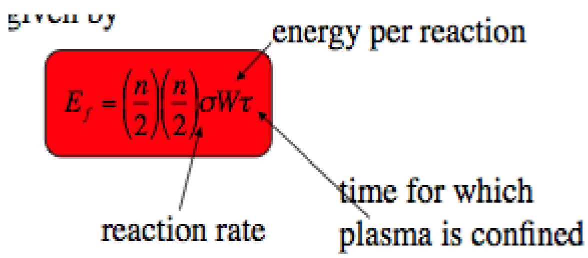
Table 5 - Important Fusion Reactions and the Resulting Energy

A high amount of energy needs to be applied to plasma to heat it up to fusion temperatures. At least 10 keV (which is known as kinetic temperature and is a correlation of the relationship between pressure and volume against average kinetic energy related to ideal gas law this is referred to as kinetic temperature) is needed to overcome the electric propulsion barrier that keeps nuclei from binding. As well as temperature the nuclei must have enough time to react to produce more energy than is put in to be considered successful. This means our density – confinement time product known, as the Lawson criterion has to create more energy out than energy put in.

Lawson Criterion

n (ion density) * *τ (confinement time)* Equation 21

As mentioned above the energy out must exceed the energy in. The energy out is measured by the equation below



Equation 22

The reaction rate is built upon something known as a cross section. The cross section is used to express the likelihood of interaction between particles and is derived from the equation below.

$$\sigma(E) = \frac{S(E)}{E} \exp(-R/\sqrt{E}) \quad \text{with} \quad R = \pi\left(\frac{e^2}{\hbar c}\right)\sqrt{2mc^2}\, Z_1 Z_2$$

Equation 23

Above E = 1/2mv^2, m = m1m2/(m1+m2), and v is the relative velocity of interacting particles. These particles have mass m1 and m2 as well as charges Z1 and Z2. The constant e denotes the elementary charge or the electric charge carried by a single proton. Constant h represents enthalpy or total energy including the internal energy. Constant c represents the speed of light. The other parameters are denoted in the table below for several reactions including the reactions in table 6. Where A is a representation of area and energy and B represents a plasma pressure to magnetic pressure ratio. The last column R shows the calculations of R in the cross section equation for each reaction.

Reaction	*A* (barns-keV)	*β* (keV^{-1})	*R* ($keV^{1/2}$)
$D-D_p$	52.6	-5.8×10^{-3}	31.39
$D-D_n$	52.6	-5.8×10^{-3}	31.39
D–T	9821	-2.9×10^{-2}	34.37
T–T	175	9.6×10^{-3}	38.41
$D-{}^3He$	5666	-5.1×10^{-3}	68.74
$T-{}^3He$	2422	4.5×10^{-3}	76.82
${}^3He-{}^3He$	5500	-5.6×10^{-3}	153.7

Table 6 - Low Energy Cross -Section Parameters

The graph below plots the calculated cross section or reactivity over energy applied.

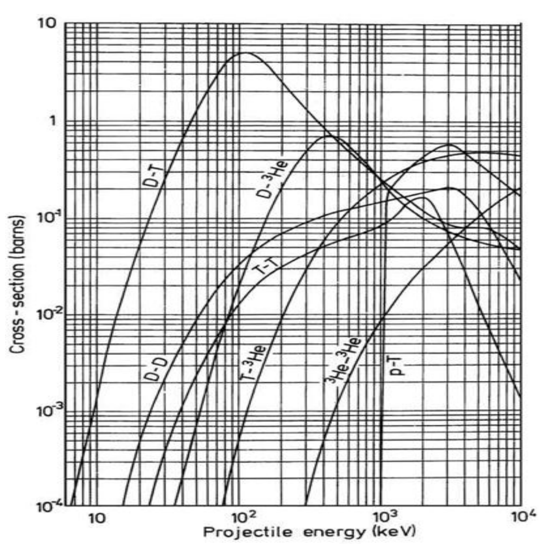


Figure 17 - Cross section of nuclear reactants over projectile energy

From analysis of the graph you can see that D-T reaction is the most reactive and requires the least amount of heat to do so. However the reaction rate requires an average of cross section and relative velocity. The reaction rates of the same reactions are graphed below over kinetic temperature.

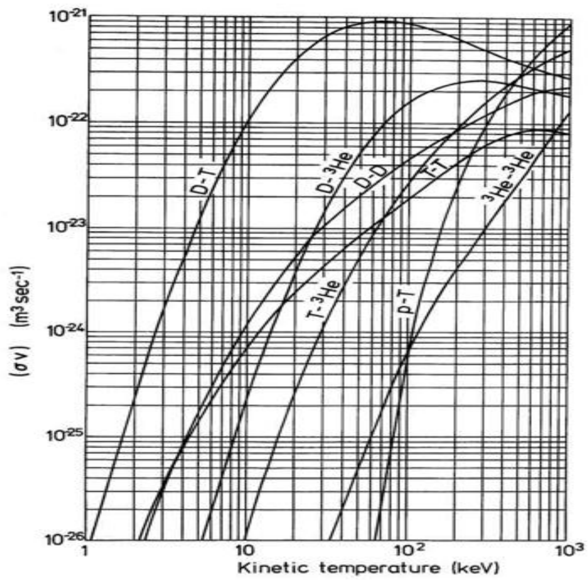


Figure 18 - Reaction Rate over kinetic temperature

The energy in (to heat the plasma) is outline in the equation below.

$$E_t = 2 \times \frac{3}{2} k_B T$$ Equation 24

Where K_b is the Boltzmann constant that relates energy and temperature at the particle level. Setting energy in and energy out equal to one another and combining like terms is represented below:

$$\frac{n^2 \sigma W \tau}{4} > 3nk_B T$$ Equation 25

Placing n and t on the left side of the inequality yields

$$n\tau > \frac{12k_B T}{\sigma W}$$ Equation 26

So we know for a D- T reaction that W is about equal to 17 MeV, we need a temperature of 10 keV, and the reaction rate of D-T is 10 ^-22 M^-3 *s. So we know we need at least 10^20 sm^-3 for a D-T reactions.

A different indication for evaluating performance of fusion plasmas is known as the triple product.

Fusion Triple Product

*n (ion density) * τ (confinement time) * T (plasma temperature)* Equation 27

The above equation is the fusion triple product it accounts for everything the Lawson criterion accounts for but additionally adds the parameter of plasma temperature.

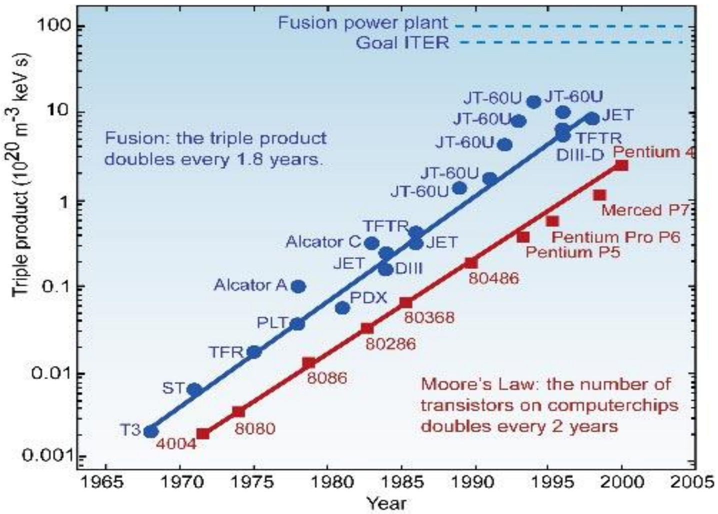


Figure 19 - Timeline of Reactor Achievements

The figure above shows the progress different rectors are making achieving the triple product. The chart shows that we are some years away before sustainable fusion is practical in a reactor.

Power density is the measure in how much power might be harnessed commercially.

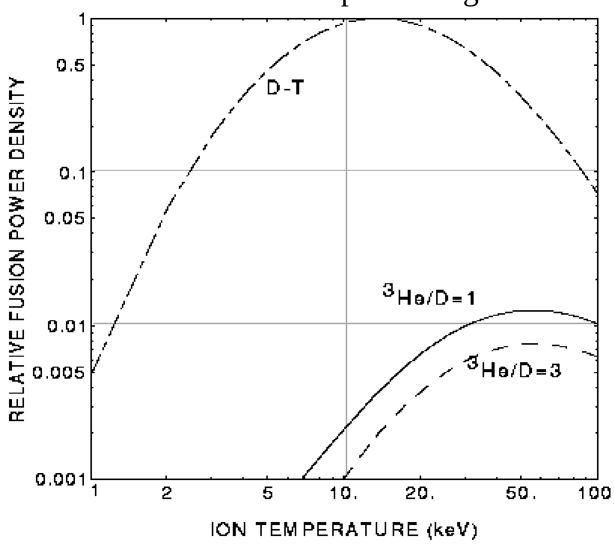


Figure 20 - Power density for D-T and Helium 3-D (from www.WISC.edu))

Figure 20 shows the power density for D-T to be superior to that of Helium-3 –D reactions. Power density represents the time rate of energy transfer per unit volume. While this favors the D-T reactions the fraction of energy that is neutrons favors He 3 – D reactions and is shown in the figure below.

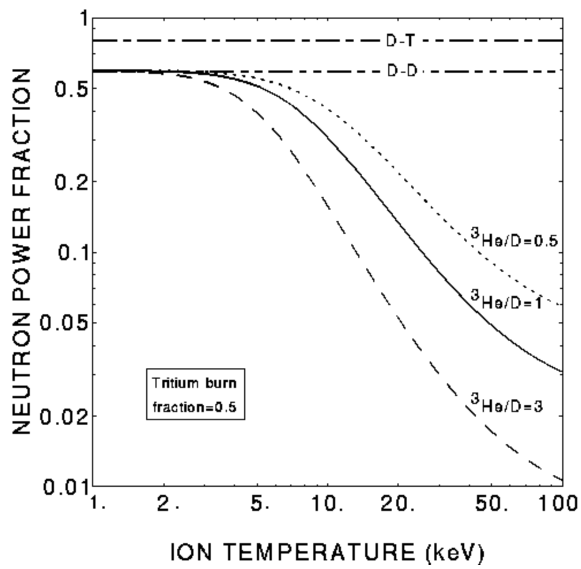


Figure 21 - Neutron Power Fraction for D-T and D-He 3 reactions

The D-T reactions and Helium-3 each have their own set of respective pros and cons. With the current technology the D-T reaction are easiest to achieve. However the D-T reaction produces a lot of free neutrons that attach to outside materials and cause radioactive waste. However the D-T reaction produces more energy that can be converted for use and profit. Most of this energy is in the form of neutrons, about 80% but still that yields a larger power density.

A free neutron is radioactive. These free neutrons have no electrical charge so they easily pass through an atom and react with nuclei to form isotopes that don't normally occur. This process induces radioactivity and is so dangerous because of the ease in which it can spread. This free neutron can cause deformation in body tissues of humans that means it needs to handled and stored with extreme caution. The free neutrons also interact with the materials of the reactor making some brittle, swelling others, and inducing low-level radioactivity. This damage to the material requires materials to be replaced more frequently than they would need to be if radioactivity was not prevalent. The graph below shows the amount of neutrons produced per MeV for several nuclear reactions.

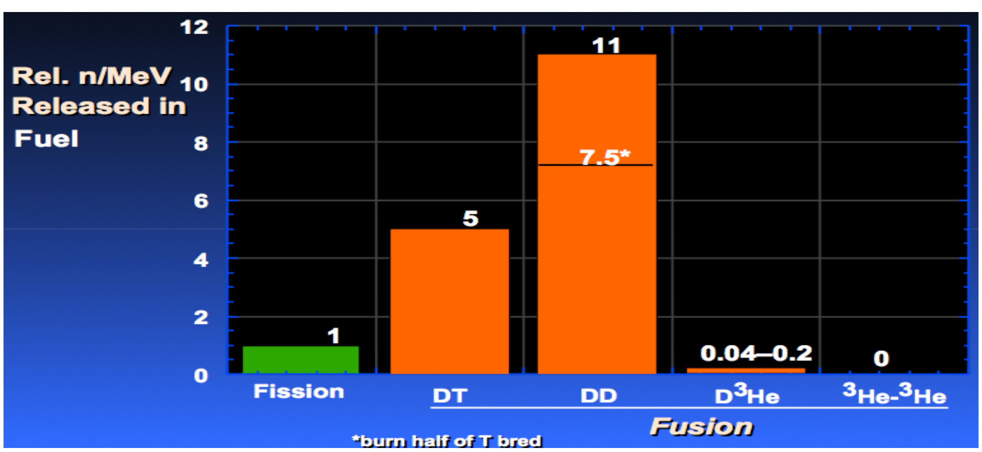


Figure 22 - Neutrons Produced by Different Nuclear Reactions

Figure 22 shows that deuterium - deuterium reactions produce, by far, the most free neutrons. Deuterium – Tritium reactions produced a little less than half of the D-D reaction. The helium -3 reactions produce virtually no free neutrons.

If we want to use large enough samples of fuel the temperature needs to be tens of millions of degrees centigrade. Under these conditions the electrons are stripped from the nucleus. The system now consists of positively charged nuclei and free electrons. The system is more commonly known as plasma. Plasma begins at 100,000 degrees centigrade. When the plasma is at a hot enough temperature the electromagnetic tendencies are overcome and nuclei begin to collide and combine. (The high heat causes the particles to move in all directions). Since these temperatures rival those of the sun containing the high heats cannot be done by a material and alternative methods need to be used.

There are two types of controlled fusion reactors they are magnetic confinement and inertial confinement. Magnetic confinement use magnetic fields to confine low-density plasma for extended periods of times at high temperatures. Magnetic confinement keeps the plasma from contacting the walls of the reactor by keeping it moving in helical paths by using magnetic force. The idea behind this method is to extend the time that ions spend close to one another in order to facilitate fusion. The most popular reactor for magnetic confinement is the tokomak fusion reactor. Inertial confinement uses laser pulses to heat small samples of high -density materials for a short period of time. The idea behind this is to hit the sample with such high energy density that they will fuse before they have time to move apart. Recently the National Ignition Facility pointed 192 lasers fired 1.3 mega joules of energy at a target containing deuterium and tritium (a new record). This resulted in a core temperature of 6 million degrees Fahrenheit. The NIF believe that a net energy gain can occur within the next two years.

Traveling to the moon is a very expensive endeavor and a lunar outpost would require a reason to make it worthwhile. Helium-3 has a potential to be that reason. Lunar soil samples show that there is at least 13 parts per billion of helium-3 in the soil (parts per billion would be 13 micrograms per kilograms of soil). This may seem like trivial amounts of helium-3 but there is only a supply of 12,000 liters this year and 8,000 liters a year for the next five years. Helium-3 has other uses as well; it can reduce temperatures to nearly absolute zero, be used in medical imaging, and can detect neutrons from nuclear devices (nuclear weapon detection). With its number of applications growing the demand will rise. A current analysis says there are 1,000,000 tons of helium three on the moon. 1 ton of helium-3 could produce 10,000 MWe-y of electrical energy. To extract helium-3 from these lunar samples the regolith would need to be mined than heated at a high enough temperature to break down the material than collect the elements in a specialized membrane.

Once Helium three is brought to earth it will not be able to solve the fossil fuel problem immediately. Implementation will be slow and Helium three will be used in other fields as well. Once the fusion parameters are advanced further an infrastructure can be installed on earth and small power plants could begin to emerge using helium three.

Both Helium-3 and D-T have positives and negatives as a source for fuel for nuclear fusion. Simply D-T reactions are easier to achieve and produce more energy however the reaction produces more harmful waste. D-He3 reactions are significantly cleaner and the energy produced is easier to convert into usable electricity. Achieving a D-T reaction is a necessary step to advance fusion technologies. However the effects of pollution in many forms can be seen all around us a cleaner more efficient source of energy should be implemented as soon as possible to avert the dangers of pollution of any type.

OBSERVATORY

Due to the need of such an early deflection, an observatory on the Moon could prove a vital tool. With the lack of atmosphere and radio noise to disrupt images, an observatory on the Moon would help to detect near Earth objects earlier and also help to receive clearer images of the trajectory and composition of the object. Furthermore a space observatory located on the far side of the moon could help to look deeper into space with more clarity than ever before.

This observatory would be similar to a free space telescope in that they both have no blurring atmosphere to cloud images but the Moon provides a solid anchor for an observatory to be placed. Radio waves emitted from celestial objects are weak and can be easily contaminated by man-made interference making them hard to read. If placed on the far side of the Moon, the observatory would be blocked from excess radio noise from Earth. Also low frequencies that bounce off the Earth‘s atmosphere would be able to be detected through the Moon‘s thin atmosphere. With an observatory placed on the moon, not only could we look more clearly out into space, but it would also provide extra protection from near Earth objects. The observatory would be able to detect near Earth objects much earlier due to the thin atmosphere and clearer images. This would allow scientists on Earth more time to devise a plan and then execute it.

NEAR-EARTH OBJECTS

Near Earth objects (NEOs) are defined as comets or asteroids whose trajectory takes them within 1.3 astronomical units of the Sun. One astronomical unit is approximately equal to the average distance between the Earth and the Sun, or 93 million miles. Earth‘s gravitational pull can force these objects off their original flight path and closer towards our vicinity. Every day our planet is bombarded with hundreds of tons of space rock and debris, most of which burns away in the upper layers of our atmosphere. Following Congressionally mandated orders, NASA has catalogued the path of any space object larger than 100m wide – the estimated size that would produce catastrophic results if it were to strike Earth. The Near-Earth Object Observations Program, commonly called "Spaceguard," discovers these objects, characterizes them, and plots their orbits to determine if any could be potentially hazardous to our planet. Until now there have been over one thousand of these size asteroids found near our planet but none likely to impact the Earth.

A somewhat recent instance of one of these large objects impacting Earth is the Tunguska event. On July 30, 1908, an object entered our atmosphere and exploded in the sky above Tunguska, Siberia, and a region in the northern hemisphere. This explosion leveled over 800 square miles of forest landscape, the equivalent power of nearly 185 Hiroshima bombs. Scientists believe that the size of the object was only 120 feet across (0.05km) but weighed approximately 220 million pounds. Many experts think the object exploded due to severe air friction from our atmosphere. Traveling around 33,000 mph, the particle heated the surrounding air to about 45,000°F; this combination of ram pressure and heat caused the rock to break apart and eventually explode 28,000 feet above the Earth. The composition of the Tunguska fragment has been widely debated ever since the event occurred. Some people believe Tunguska to be an asteroid that broke apart in space and then once again above Earth, however there is no evidence of fragments anywhere in the region. Others believe it‘s a comet that had disintegrated after entering our atmosphere which would explain the bright night skies that followed a few days after the impact.

Comets are primarily made up of water and dust and, when they enter our region usually burn away in the upper atmosphere. These loose water particles freeze in the low temperatures of the mesosphere and form bright, noctilucent clouds. This type of cloud was observed over the Asian and European skies for days after the Tunguska impact. Additionally, the Beta Taurid meteor shower was also in its peak during times that coincide with the impact. Just last month, an expedition led by Vladimir Alexeev (Trinity Research Labs) put an end to the 100 year dispute. Using a new instrument called Ground-Penetrating Radar (GPR) the scientists searched nearby swamps and sinkholes for any strange objects up to 100 meters down. The GPR uses electromagnetic-radiation pulses in the microwave bandwidth to image any underground surface; its range is limited by the electrical conductivity of the soil. At the bottom of the Suslov crater they found an impact site that contained permafrost and the solid ice nucleus made of water, methane and other gases and space particles. This find verifies that the object was neither an asteroid nor a meteorite, but in fact a comet.

CARGO

To supply the International Space Station, large unmanned cargo transports are sent to the station filled with supplies. These cargo transports include materials for experiments, spare parts and provisions for the crew. The Kounotori 2 (or HTV-2) is a Japanese cargo vessel that arrived at the International Space Station on January 27, 2011. The vessel contained 5.3 tons of supplies consisting of spare system components (51% of cargo weight), foods (24%), science experiment materials (10%), crew commodities (8%), and water (7%). Similar vessels are owned by Russia and the ESA. These autonomous spacecrafts will be very useful to the colonization of the moon.

LAUNCHING PAD

The Moon can be used as an effective “launch pad” due to its lower gravity and also no atmosphere, which means no drag. The escape velocity is the speed at which the kinetic energy plus the gravitational potential energy of an object is zero. It is commonly described as the speed needed to "break free" from a gravitational field. The term escape velocity is actually a misnomer, as the concept refers to a scalar speed that is independent of direction. In practice the escape velocity sets the bar for any rocket aiming to bring a satellite beyond earth orbit. It gives a minimum delta-v budget for rockets when no benefit can be obtained from the speeds of other bodies, for example on interplanetary missions where a gravitational slingshot may be applied.

$$V_e = \sqrt{(2GM/r)} \qquad \text{Equation 28}$$

Where G is the universal gravitational constant, r is the radius of the celestial body, and M is the mass of the celestial body. The escape velocity of Earth is 11km/s. The escape velocity of the Moon is only 21.43% of that, at 2.4km/s. This means that the required burn time for lifting off of the Moon would be roughly five times less than lifting off from the Earth which means, provided the mass flow rates are equal, the vehicle would have to burn roughly five times less propulsion.

The Space Shuttle has two solid rocket boosters. The propellant for each weighs approximately 1,100,000 lb (500,000 kg). The inert weight of each is approximately 200,000 lb (91,000 kg). That is 2.2 million pounds of propulsion just from those two boosters. The External Tank carries about 1.6 million pounds of propulsion. The mass-payload to mass-propulsion ratio would be much higher from the Moon rather than the Earth, so ideally a deep space mission could leave from the Moon with much less ΔV_T.

Once having left the moon, solar sails could be used to aid in deep space explorations. The use of solar sails uses the forces from a star to push enormous ultra-thin mirrors to high speeds. There are two sources of solar forces, the first is radiation pressure, and the second is due to solar wind. The radiation pressure is much stronger than the wind pressure. In 1924, the Russian space engineer Friedrich Zander proposed that, since light provides a small amount of thrust, this effect could be used as a form of space propulsion requiring no fuel. Einstein proposed - and experiments confirm - that photons have a momentum p=E/c, hence each light photon absorbed by or reflecting from a surface exerts a small amount of radiation pressure. S divided by the square of the speed of light in free space is the density of the linear momentum of the electromagnetic field. The time-averaged intensity <s > divided by the speed of light in free space is the radiation pressure exerted by an electromagnetic wave on the surface of a target:

$$P_{rad} = \langle s \rangle / c \qquad \text{Equation 29}$$

This results in forces of about 4.57x10−6 N/(m^2) for absorbing surfaces perpendicular to the radiation in earth orbit, and twice as much, if the radiation is reflected. This was proven experimentally by Russian physicist Peter Lebedev in 1900.

The solar wind averages 6.7 billion tons per hour at 520 km/s with "slow" low energy coronal ejections reaching 400 km/s and "fast" higher energy ejections averaging 750 km/s. At the distance of the earth, this results in average solar wind pressure of 3.4×10−9 N/(m^2), three orders of magnitude less than the photonic radiation pressure. Still the solar wind dominates many phenomena because its interaction cross section with gases and charged particles is about 10^9 times larger than that of the photons.

Both of these forces are small and decrease with the inverse square distance from the sun. Even large sails produce minute acceleration, but over time, sails can build up considerable speeds. Because the force on the sails and the force of gravity from the sun both vary as inverse square functions, solar sail vessels can be rated by the ratio of the sail's force divided by the gravitational force. Solar sail vessels with the same rating are able to follow the same trajectories.

Solar sails don't work well, if at all, in low Earth orbit below about 800 km altitude due to erosion or air drag. Above that altitude they give very small accelerations that take months to build up to useful speeds. Solar sails have to be physically large, and payload size is often small. Deploying solar sails is also highly challenging to date.

On 21 May 2010, the Japan Aerospace Exploration Agency (JAXA) launched the "IKAROS" (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) spacecraft, which deployed a 200 m^2 polyimide experimental solar sail on June 10. In July, the next phase for the demonstration of acceleration by radiation began. On 9 July, it was verified that IKAROS collected radiation from the sun and began photon acceleration by the orbit determination of IKAROS by range-and-range-rate (RARR) that is newly calculated in addition to the data of the relative accelerating speed of IKAROS between IKAROS and the Earth that has been taken since before the Doppler Effect was utilized. The data showed that IKAROS appears to have been solar-sailing since 3 June when it deployed the sail. IKAROS has a diagonal spinning square sail 20 m (66 ft) made of a 7.5-micrometer thick sheet of polyimide. A thin-film solar array is embedded in the sail. Eight LCD panels are embedded in the sail, whose reflectance can be adjusted for attitude control. IKAROS will spend six months traveling to Venus. IKAROS was successfully launched together with Akatsuki (the Venus Climate Orbiter) aboard an H-IIA rocket from the Tanegashima Space Center on 21 May 2010. IKAROS spun at 20–25 revolutions per minute and finished unfurling its sail on 11 June 2010. The craft contains two tiny ejectable cameras, DCAM1 and DCAM2. DCAM2 was used to visualize the sail after deployment on 14 July 2010. On 9 July, JAXA confirmed that IKAROS is being accelerated by its solar sail.

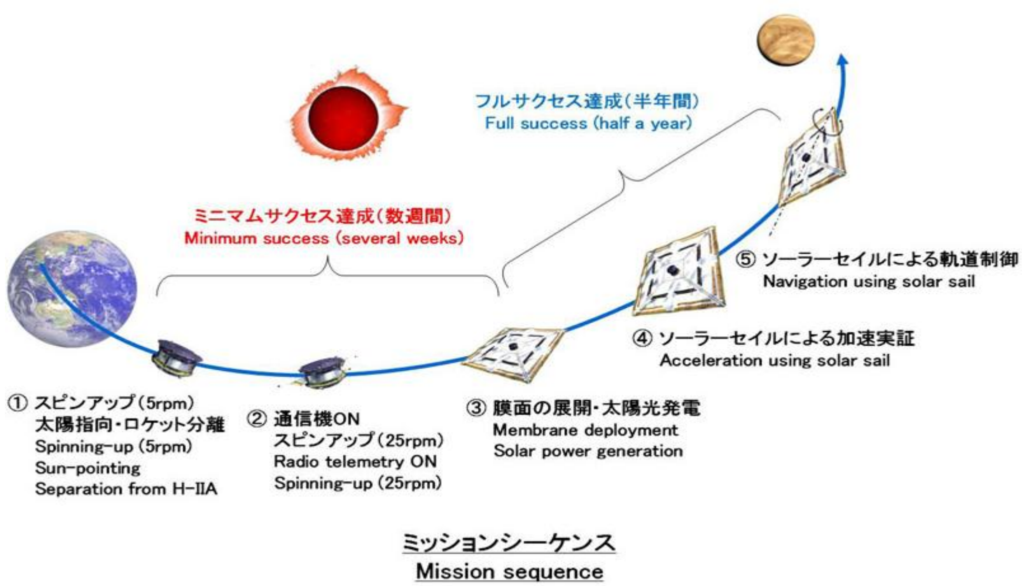


Figure 23 - Path of a Solar Sail

The membrane is deployed, and kept flat, by its spinning motion. Four masses are attached to the four tips of the membrane in order to facilitate deployment. Deployment is in two stages. During the first stage, the membrane is deployed statically, and during the second stage, dynamically. This deployment method can be realized with simpler and lighter mechanisms than conventional mast or boom types as it does not require rigid structural elements.

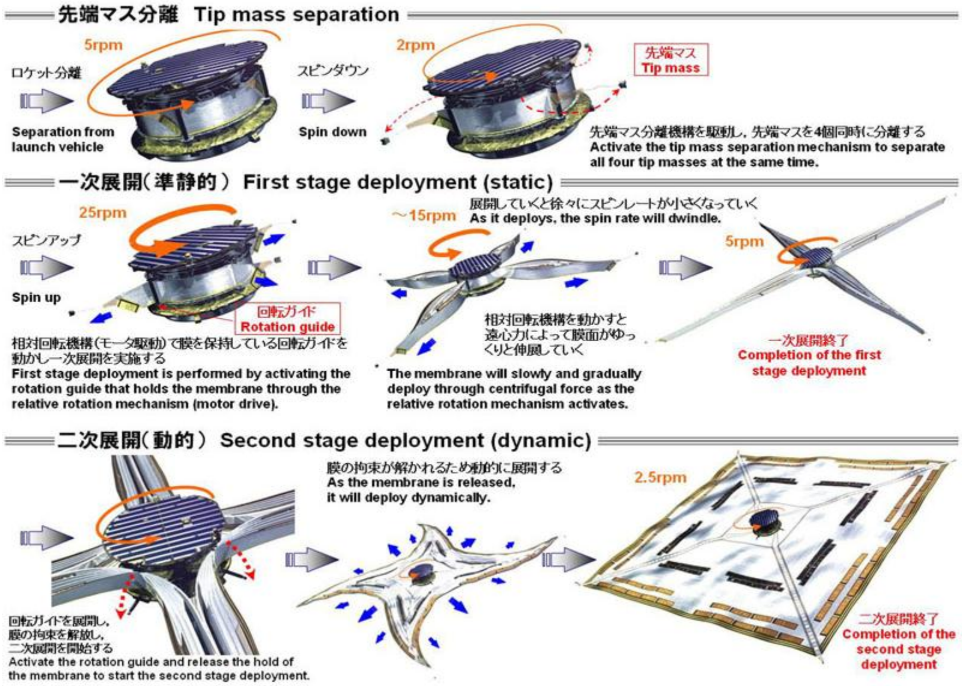


Figure 24 - Deploying a Solar Sail

Upon successful completion of the mission, the second mission will take place in the late 2010s. It will involve a large sized solar power sail with a diameter of 50m, and will have integrated ion-propulsion engines. The destinations of the spacecraft will be Jupiter and the Trojan asteroids. Solar sail missions are also being studied in the United States and in European countries. The JAXA website states: “JAXA will lead future solar system exploration using solar power sails. Our missions will lead to lower cost in the solar cells market, whose growth is a key factor for global warming prevention. Those low-cost solar cells are also the foundation of future solar power satellite systems.”

Experiments on the Moon

If the scientist’s theories are correct and this ice has been frozen in the permanently shadowed crater for billions of years, ice core samples could help uncover the history of our solar system. Using different methods to date and analyze the ice, scientists could discover how the Moon and surrounding planets were formed.

Space is an intriguing place to perform certain experiments because of the natural vacuum that is not present on Earth. Experimentation in a vacuum has helped to lead to light bulbs, integrated circuits, particle acceleration, and even weather prediction. The International Space Station was built to conduct such experiments in space. These experiments could also be performed on the surface of the moon.

The moon is a prime spot for these experiments that require low gravity and a thin atmosphere. Zeolite crystal growth for example is much more effective in low gravity. These crystals grown in the microgravity of space have been found to grow larger and contain fewer imperfections than those grown on Earth. Zeolite crystals are considered to be a material that can be easily engineered. They can, within broad limits, be made for specific selective applications in adsorption, separation, and catalytic processes. These crystals are used in the production of gasoline though a chemical process called catalytic cracking. Zeolites are also often used in filtration systems for large municipal aquariums to remove ammonia from the water along with many other applications. While small crystals are useful in catalytic processes, they cause a severe disadvantage in adsorption, separation and ion-exchange processes. The low gravity lunar surface would provide an ideal location with low gravity where many zeolite crystals can be grown. The moon is also a prime location to conduct dangerous experiments. Chemical, biological, and nuclear testing could be conducted without endangering the public population.

While on the moon different experiments could be conducted to help us learn more about the history of our solar system. Deep inside craters that are forever cast in shadow is ice that scientists believe has been present since the creation of our solar system. Ice core samples from this dated ice could help to enlighten us on the formation of our solar system.

If a private company were to establish an outpost on the moon with laboratories for experiments, they could potentially rent the lab space to other private or government funded companies who want to conduct experiments in space but do not want to establish their own lunar outpost. This would be a good way for a company to make money from an outpost on the moon.

SPACE BASED SOLAR POWER

Electromagnetic waves can be used for wireless power transmission (WPT). The difference between the electromagnetic waves communication systems use and WPT is the efficiency of the signal. WPT is usually a point A to point B transmission using microwaves to deliver energy. One potential application of WPT is a solar powered satellite (SPS). Solar powered satellites could be in geostationary earth orbit (GEO). GEO is an orbit above the equator at an altitude of about 22,000 miles. The orbit also matches the period of earth's rotation so the satellite appears stationary from a person viewing it from the ground.

Once the solar energy is collected it has to be sent to earth in the form of microwaves. To send microwaves to earth from a satellite the electricity collected needs to be used to generate and amplify microwaves. This can be done using either a microwave tube or a semiconductor amplifier. A magnetron is an example of a microwave tube and is the power behind the microwave oven. A magnetron uses magnets to deter the flow of electricity from an anode to a cathode. This combination of electrical flow and magnetism gives the electrons a circular motion that results in microwaves. The magnetron has its advantages and disadvantages. The magnetron has a higher DC-RF conversion efficiency; it costs less, and has a smaller weight/power ratio than semiconductor devices. The magnetron also has a wide oscillation bandwidth and operates at various frequencies. The wideband oscillation will lead to a fluctuation of the microwave beam because of degradation of its frequency and phase stability. The spurious noise will interfere with other communication systems. Using a magnetron with a dc stabilized power supply and the filament current turned off during operation more desirable results are obtained.

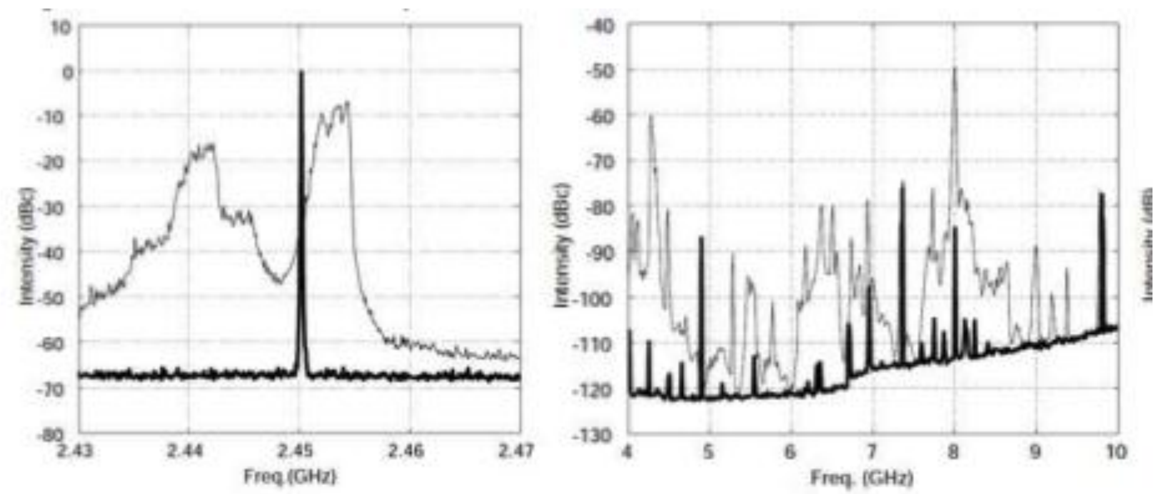


Figure 25 - Experimental Results for Fundamental bands and Spurious Noise

Figure 25 above depicts two graphs. The graph on the left shows the insufficient frequency from the wideband oscillations with the lighter line and the black line shows the capability the magnetron has using the improved method of performance indicated by the clean spike at 2.45 GHz which is our ideal operating frequency. The graph on the right shows the original spurious noise in the lighter color and the spurious noise output using the new method of operation for the magnetron in black. The improved method of running the magnetron provides a significant decrease in the amount of spurious noise created. A Compact Microwave Energy Transmitter (COMET) uses this method to be more efficient and has a power to weight ratio of 25 g/W. Another method for microwave generation/transmission is the Microwave Power Module (MPM). The MPM combines the technology of traveling wave tube (TWT) and semiconductor amplifiers.

In order to transmit these microwaves to a point on earth an antenna is needed. Since accuracy is important a phased array will be used. A phased array is a group of antennas that take pieces of a signal in such a varied way that the radiation pattern of the array is more directional. Directivity is an essential antenna limitation. It is a measure of how accurate an antenna is. The normalized radiation pattern of an antenna is a function of θ and ϕ in the spherical coordinate system. The normalized radiation pattern is a regular radiation patterns except the magnitude is scaled to 1. Therefore the equation is the maximum magnitude over the average power radiated in any direction.

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\left|F(\theta,\phi)\right|^2 \sin\theta d\theta d\phi}$$ Equation 30

Equation 19 above shows the directivity equation. The units are in decibels (dB) and in the spherical coordinate system.

A rectenna is comprised of an antenna and a system to rectify a microwave into DC power. Rectennas run at 70-90% efficiency at 2.45GHz or 5.8GHz microwave input. Rectenna is not the only option for power receiving a Cyclotron Wave Converter (CWC) is also available. The CWC serves the same purpose as the rectenna but accomplishes the goal using a parabolic antenna instead of a phased array.

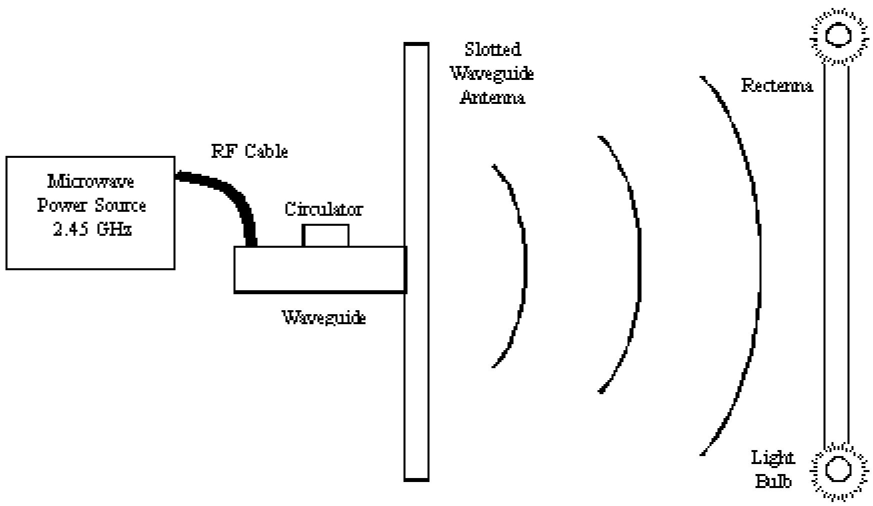


Figure 26 - Experimental Results for Fundamental bands and Spurious Noise

Figure 26 above visualizes the WPT process using a conceptual diagram.

Instead of using a satellite in GEO the moon can be used as your base to collect solar power. Dr. David Criswell is an advocate for lunar solar power and believes it can be used as a practical source of renewable energy. Dr. Criswell states that the lunar surface receives 13,000 TW's of solar power. His idea requires the limbs of moon to be covered in PV arrays in order for the system to always be collecting solar power and than sending it to earth via a series of satellites. Criswell has projected that by 2050 20 TW of electrical power could be produced and 1,000 TW of electrical power produced a year by the year 2070. His idea requires an infrastructure on the moon capable of being able to take natural lunar resources and turn those resources into the materials needed for the lunar solar power process. Dr. Criswell believes that within 12 years his idea would breakeven. Lunar solar power might not be viable as the lone reason to create a lunar outpost but could certainly be a lucrative opportunity once an infrastructure is established.

LUNAR MATERIALS

The aerospace industry has always been dependent on the materials industry. Engineers are continually searching for stronger and lighter materials as well as materials that can block radiation and not be compromised under either high temperatures or intense maneuvers. In this section we examine harvesting metals from the moon's surface and their potential uses, the properties of materials that can be used for space travel in the future, and the future development of complex materials including carbon nanotubes, C60, and smart materials.

HARVESTING METALS FROM THE MOON'S SURFACE

The moon's surface is made up of igneous, or fire-formed, rocks similar to our lava-formed rocks on Earth. A byproduct of this volcanic activity, the basalt rocks were formed when the molten rock cooled very rapidly. Since the first Apollo missions where they began the collection of lunar regolith, scientists have identified several types of construction materials that can be produced using only the materials found on the moon and simple heating and cooling techniques. Materials such as sulfur concrete, cast basalt, fiberglass, cast glass and other metals have been produced and could be used as radiation-shielding construction supplies. Additionally, the silicon could be harvested and made into monocrystalline silicon solar panels that could be used to power any base electronics.

A lunar highland mineral, anorthite, is similar to the mineral bauxite that is used on Earth to 'smelt' out aluminum. Smelting is the process of metal extraction that uses electricity or heat to create super-high temperatures that extract metals form an ore. Anorthite consists of aluminum, calcium, silicon and oxygen. Earth's smelters can produce pure aluminum, calcium metal, oxygen and silica glass from anorthite rock. Since anorthite covers up to 95% of the lunar highlands it is an abundant resource that can be exploited for its flexibility. It should also be noted that aluminum powder burned with oxygen gas is the fuel source of many solid rocket boosters. This material could therefore provide humans with a supply of fuel for missions that take place on the moon. Carrying so much fuel to the Moon from Earth would be extremely expensive and impractical. A by-product of aluminum smelt production is calcium metal, a better conducting substance than copper which could be used to fabricate wiring and other electrical equipment. Figure 27 below shows the composition of lunar soil found by NASA through samples collected during the Apollo missions.

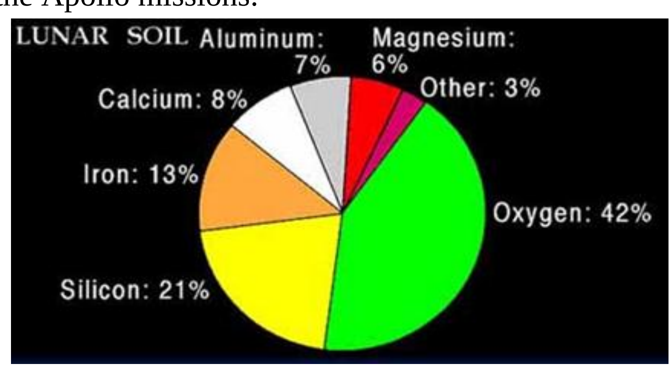


Figure 27 - Composition of the Moon's Regolith

Building Materials

Recently, seven Virginia Tech students used a type of volcanic ash similar to regolith to build bricks that could lay the foundation of a moon dome. A doctoral student there, Eric Faierson says the simulated regolith (which came from NASA) is volcanic ash mixed with other materials made to mimic the moon's surface. The team combined the faux moon ash with powdered aluminum and mixed the two together in a silica crucible. The group then put a nickel-chromium wire into the mixture and heated it to 2700º F; this started a thermite reaction that spread through the amalgam and turned it into a solid brick. The moon-brick material turned out to be nearly as strong as concrete - able to bear almost 2500 pounds per square inch. However trying to use these bricks with mortar holding them together could prove problematic on the moon. Thus, the team decided on creating a dome that would support its own weight, eliminating the need for any mortar or glue. Each layer up would simply require a specific mold for that shape so as to fit perfectly with all adjacent blocks. The dome design could be an ideal one for the lunar surface, not only because it requires no mortar, but also because the moon's weak gravity means that the building will have to cope with less downward force.

A moon-brick dome would obviously not be airtight and their ideal use would be to cover the polymer domes that NASA has proposed as possible lunar settlement structures. Moon-rock bricks could protect the building from meteorites that bombard the lunar surface. They might even be able to block some harmful forms of cosmic radiation; the Earth's magnetosphere blocks this radiation, but moon settlers would be vulnerable. So far, the team has only tested the bricks with deflecting neutron radiation but the results look promising.

One problem on the moon is that nitrogen will not be readily available unless harvested. Additionally, temperatures fall below zero on the surface of the moon and this could extinguish the reaction.

Building a Better Shield

To build a shield, you need one that absorbs or at least fragments more of the radiation -- keeping some of it from ever reaching space faring crews and rendering it less harmful so as to reduce their radiation exposure to acceptable levels. To build better shields, you need new materials and a better understanding of the physics of the particle interactions with different materials. The search for these materials is underway by the Radiation Shielding Program -- part of a strategy of the NASA Office of Biological and Physical Research to limit space crews' radiation exposure.

"To solve this complex radiation challenge, we have assembled a team of experts from multiple private, public and educational institutions," said Ed Semmes, who manages the Radiation Shielding Program at NASA's Marshall Space Flight Center in Huntsville, Ala. "Our team includes engineers, materials scientists and physicists from the Marshall Center and from Langley Research Center in Hampton, Va."

The team is examining new shielding materials that not only block and/or fragment more radiation than aluminum -- the material currently used to build most spacecraft structures -- but also are lighter than aluminum. Spacecraft designers have to be able to shape shielding materials to make various parts of the spacecraft. The material must protect the crew from radiation, and it must also deflect dangerous micrometeoroids. The shielding must be durable and long lasting -- able to stand up to the harsh space environment.

Polyethylene is a good shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation. In fact, researchers have been studying the use of polyethylene as a shielding material for some time. One of several novel material developments that the team is testing is reinforced polyethylene. Raj Kaul, a scientist in the Marshall Center's Engineering Directorate, previously has worked with this material on protective armor for helicopters.

"Since it is a ballistic shield, it also deflects micrometeorites," Kaul says. "Since it's a fabric, it can be draped around molds and shaped into specific spacecraft components."

Kaul makes bricks of the material by cutting the fabric and layering 200 to 300 pieces in a brick-shaped mold in his laboratory at the Marshall center. He then uses a vacuum pump to remove air and prevent bubbles in the material, which would reduce its strength. The material is "cooked" in a special oven called an autoclave, which heats the material slowly to 200 degrees Fahrenheit while putting it under pressure of 100 pounds per square inch using nitrogen gas. The combination of heat and pressure causes the chemical reaction that bonds the layers together to form a brick weighing about half as much as a similar piece of aluminum.

"Fiber is the secret of the material's strength," explains Kaul. "Bulk materials usually are not as strong because they are more likely to have defects. A spider's web is strong because it is made of individual fibers."

But building a better shield is only half the answer to the problem. If too much shielding material is used, the spacecraft becomes way too heavy to get off the ground. So NASA is also working on medical countermeasures that limit the effects of radiation on space crews. The Space Radiation Health Project at NASA's Johnson Space Center in Houston involves scientists nationwide at universities and medical centers. They are investigating how space radiation damages cells and tissues such as the eyes, brain and internal organs. This information can be used to develop effective medical treatments that limit damage done by radiation exposure.

CES EduPack

We used CES EduPack 2010 by Granta – Material Intelligence (courtesy of WPI licensing agreement) to examine a large amount of materials a bit more closely. Using the "Aerospace" Database and materials from MaterialUniverse: Aerospace Materials selection, the list of materials was narrowed down to 307 potential materials to be used. Since we are always looking to minimize costs when possible, and also trying to minimize weight whenever possible, we did a material analysis with density as the x-axis and price as the y-axis.

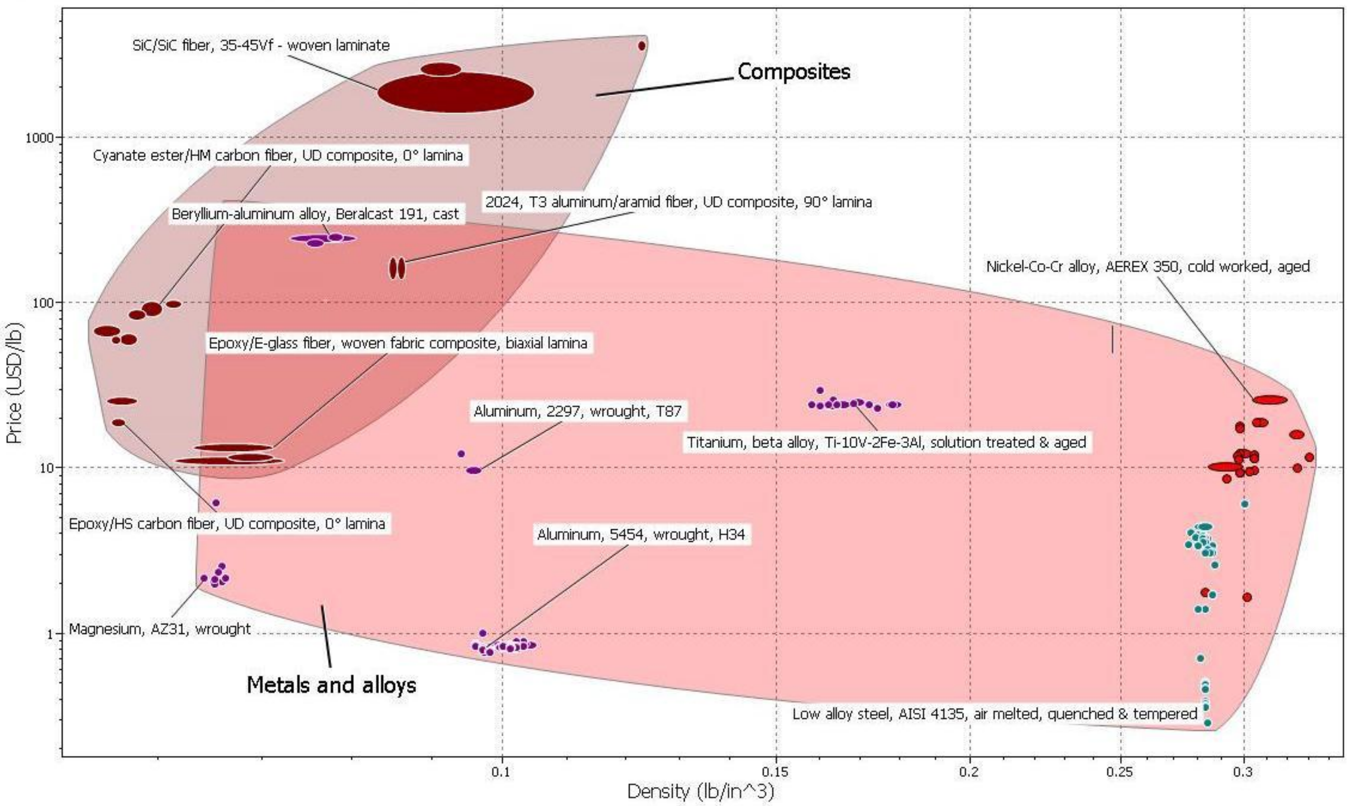


Figure 28 - Price vs. Density graph

From here we decided to cut down on the available materials by only looking at the lighter, cheaper materials. We limited the maximum density to .2 (lb/in^3) and limited the maximum price to 100 (USD/lb). This limited our results to 194. The updated graph using these conditions is shown on the next page in Figure 29.

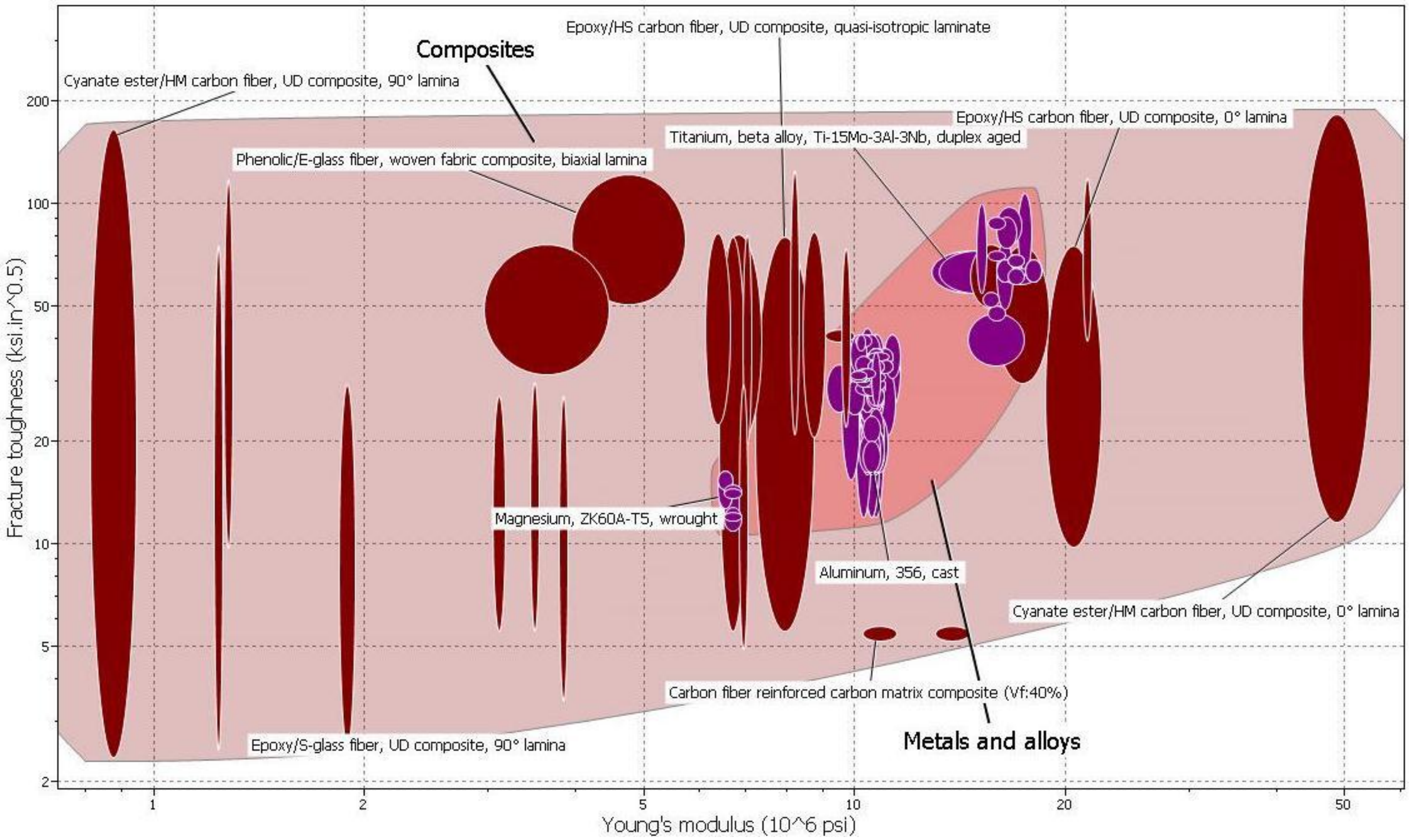


Figure 29 - Fracture Toughness vs. Young's Modulus

Above is a graph of the remaining materials graphed with respect to Young's modulus and fracture toughness. Young's modulus is, also known as the tensile modulus, is a measure of the stiffness of an isotropic elastic material. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds. It can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material.

Young's modulus, *E*, can be calculated by dividing the tensile stress by the tensile strain:

$$E \equiv \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\sigma}{\varepsilon} = \frac{F/A_0}{\Delta L/L_0} = \frac{F L_0}{A_0 \Delta L} \quad \text{Equation 31}$$

Where E is the Young's modulus (modulus of elasticity), F is the force applied to the object, A_0 is the original cross-sectional area through which the force is applied, ΔL is the amount by which the length of the object changes, L_0 is the original length of the object.

Fracture Toughness is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for virtually all design applications. It is denoted K_{Ic} and has the units of Pa(√m).

Next we decided to apply some limiting factors to these results, limiting the minimum fracture toughness to 10 (ksi.in^.5) and the minimum young's modulus to 10 (10^6) psi. 161 passed this time, with different types of aluminum taking 133 of those entries.

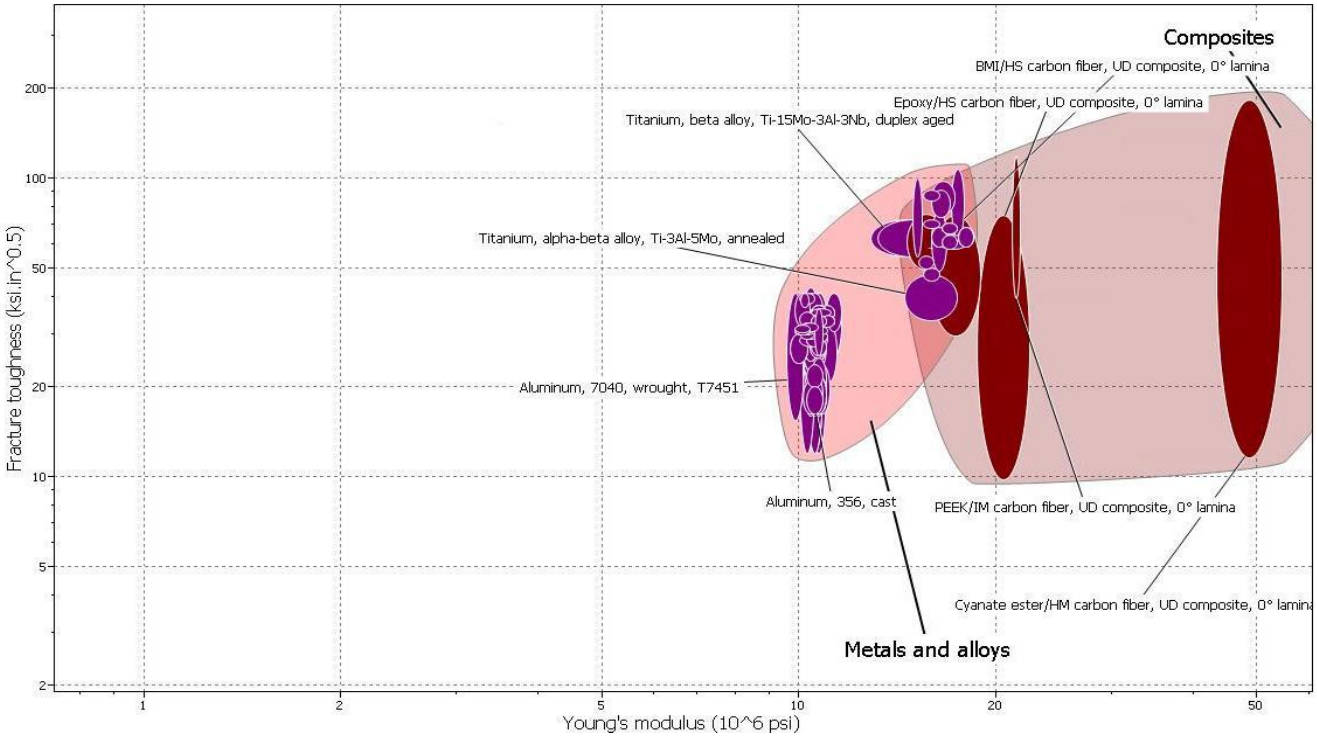


Figure 30 - Fracture Toughness vs Young's Modulus - with limiting factors

Since Aluminum is the generally the standard in air and space travel, we have some new materials to consider: Many types of Titanium, BMI/HS carbon fiber, Cyanate ester/HM carbon fiber, Epoxy/HS carbon fiber, and PEEK/IM carbon fiber.

C60 – BUCKMINSTERFULLERENE

Buckminsterfullerene is the largest matter to have been shown to exhibit wave-particle duality. Wave-particle duality postulates that all matter exhibits both wave and particle properties. A central concept of quantum mechanics, this duality addresses the inability of classical concepts like "particle" and "wave" to fully describe the behavior of quantum-scale objects.

The structure of a buckminsterfullerene is a truncated icosahedron made of 20 hexagons and 12 pentagons (like a traditional soccer ball), with a carbon atom at the vertices of each polygon and ka bond along each polygon edge. The van der Waals diameter of a C60 molecule is about 1 nanometer (nm). The van der Waals radius, rw, of an atom is the radius of an imaginary hard sphere which can be used to model the atom for many purposes. The nucleus to nucleus diameter of a C60 molecule is about 0.71 nm.

Each carbon atom in the structure is bonded covalently with 3 others. Carbon atoms have 6 electrons, meaning their electronic structure is u2,4. To become stable, the carbon atom needs

8 electrons in its outer shell, and covalently bonding with 3 other atoms will only make 7 electrons in its outer shell. This means that the one unbonded electron on every carbon atom is free to float around all of the compound's atoms. Electrons carry charge, so this free electron movement means that the buckminsterfullerene can conduct electricity very well. This, because of its size, makes it very useful in nanotechnology.

"The buckyball, being the roundest of round molecules, is also quite resistant to high speed collisions. In fact, the buckyball can withstand slamming into a stainless steel plate at 15,000 mph, merely bouncing back, unharmed. When compressed to 70 percent of its original size, the buckyball becomes more than twice as hard as its cousin, diamond."

In 1991, Science magazine dubbed the Buckyball "molecule of the year," professing it "the discovery most likely to shape the course of scientific research in the years ahead," a statement that, years later, does not appear unsubstantiated. Studies exploring the extraordinary characteristics of Buckyballs and potential uses for them are ongoing and the molecules may eventually wind their way into daily life as practical applications are developed. One of the most promising areas of Buckyball research is in the realm of materials science, many scientists believing that the extremely stable molecules could yield new and improved lubricants, protective coatings, and other materials. But, even more exciting to some are the possible materials that may be produced by combining the carbon framework of the Buckyball with different atoms. The process of knocking one or more carbon atoms out of the Buckyball structure and replacing it with metal atoms is known as doping, and the molecule in its altered form is often referred to as a dopeyball. The electrical and magnetic properties of dopeyballs have been the subject of intense study, which has already resulted in the discovery that potassium-doped Buckyballs are capable of superconducting at 18 K and those doped with rubidium superconduct at 30 K.

In addition to doping Buckyballs with other atoms, the hollow structure of the geodesic molecules makes it possible to trap atoms inside them like a molecular cage. This strange capability of Buckyballs has caught the attention of the medical community. Indeed, many researchers believe that eventually Buckyballs may be used to deliver medicines to specific tissues and cells, such as those that have been attacked by bacteria, viruses, or cancer, protecting the rest of the body from the toxic effects of potent pharmaceuticals. This same concept is currently being used to develop improved Medical Resonance Imaging (MRI) contrast agents and image enhancers that exploit the carbon cage of a Buckyball to shield patients from the radioactive materials inside. There are also many non-medical possibilities for atom-filled Buckyballs, which are termed endohedral metallofullerenes (EMFs) when the atoms trapped inside are metallic. For instance, EMFs are well on their way to being utilized in organic solar cells and may one day be crucial components of nanoelectronic devices, which many predict will eventually revolutionize the modern communications industry. Some EMFS have also shown potential for use as chemical catalysts that could be delivered to support surfaces in novel ways.

Since the discovery of fullerenes in 1985, scientists have discussed a myriad of possible uses for these unusual molecules. Just some of these possibilities are described here.

Chemical sponges

Medical researchers believe that fullerenes could be put to work as tiny chemical sponges, mopping up dangerous chemicals from injured brain tissue. Excess production of free radicals (e.g., peroxide) in the brain following a head injury or a stroke destroys nerve cells. Buckyballs, made soluble in water, appear able to ‘swallow’ and hold free radicals, thereby reducing the damage to tissue.

Nanotubes in microscopes

Buckyball discoverer Richard Smalley and colleagues have used nanotubes as chemical probes in a scanning-force microscope. The microscope relies on a tiny tip that detects and skims the surface of target molecules. The great resilience of fullerenes means that the tube springs back into its original shape when bent.

Buckyballs in miniature circuits

A supercomputer the size of a paperback is the ambition of European researchers who have managed to attach a single buckyball to a sheet of copper. The scientists compressed the buckyball by 15 per cent, improving electrical conductivity by more than 100 times compared to the undisturbed molecule. A tiny electronic component like this could make miniature circuits feasible.

Lubricants, catalysts and superconductors

Other exciting potential uses of fullerenes include buckyballs behaving as 'molecular ball bearings' allowing surfaces to glide over one another. Fullerenes with metal atoms attached to them might function as catalysts, increasing the rate of important chemical reactions. Scientists know that buckyball compounds with added potassium act as superconductors at very low temperatures.

Molecular sieves

Because of the way they stack, buckyballs could act as molecular sieves, trapping particles of particular sizes while leaving others unaffected. Scientists talk of designing sieve-like membranes from buckyballs that allow biological materials to pass through, but not larger particles such as viruses. This would be useful for handling transplant organs, for example.

Xerox Buckyballs

In the United States, Xerox owns patents for using buckyballs to improve resolution of photocopies. They are 1000 times smaller than the particles used in conventional photocopier toner.

After the astrophysicists D.R. Huffmann and W. Kratschmer managed to produce larger quantities of fullerenes in 1990, scientists further investigated the structure and characteristics of buckyballs. Research on buckyballs has led to the synthesis of over 1000 new compounds with exciting properties, and over 100 patents related to buckyballs have been filed in the US. In addition, an important new material, nanotubes, has exploded onto the scientific scene in recent years. The discovery and manufacture of nanotubes resulted directly from research on buckyballs. Finally, although buckyballs have not yet been used in any practical applications, partly due to the high cost of material, researchers are using buckyballs to learn more about the history of our world, and companies are devising some interesting uses for buckyballs even today.

Carbon Nanotubes

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than any other material. These cylindrical carbon molecules have novel properties, making them potentially useful in many applications in nanotechnology, electronics, optics, and other fields of materials science, as well as potential uses in architectural fields. They may also have applications in the construction of body armor. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors.

Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to 18 centimeters in length (as of 2010).

"Conceptually, single-wall carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder. A multiwall carbon nanotube (MWCNT) can similarly be considered to be a coaxial assembly of cylinders of SWCNTs, like a Russian doll, one within another; the separation between tubes is about equal to that between the layers in natural graphite. Hence, nanotubes are one-dimensional objects with a well-defined direction along the nanotube axis that is analogous to the in-plane directions of graphite." —M. S. Dresselhaus, Department of Physics and the Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

The dimensions are variable (down to 0.4 nm in diameter) and you can also get nanotubes within nanotubes, leading to a distinction between multi-walled and single-walled nanotubes. Apart from remarkable tensile strength, nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic). [CMP]

Nanotubes can be either electrically conductive or semiconductive, depending on their helicity, leading to nanoscale wires and electrical components. These one-dimensional fibers exhibit electrical conductivity as high as copper, thermal conductivity as high as diamond, strength 100 times greater than steel at one sixth the weight, and high strain to failure.

Many potential applications have been proposed for carbon nanotubes, including conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nanometer-sized semiconductor devices, probes, and interconnects. Some of these applications are now realized in products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is clouded by controversy. Nanotube cost, polydispersity in nanotube type, and limitations in processing and assembly methods are important barriers for some applications of single-walled nanotubes.

Smart Materials

Smart materials are materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields.

There are a number of types of smart material, some of which are already common. Some examples are as following:

- Piezoelectric materials are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied.
- Shape memory alloys and shape memory polymers are materials in which large deformation can be induced and recovered through temperature changes or stress changes (pseudoelasticity). The large deformation results due to martensitic phase change.
- Magnetostrictive materials exhibit change in shape under the influence of magnetic field and also exhibit change in their magnetization under the influence of mechanical stress.
- Magnetic shape memory alloys are materials that change their shape in response to a significant change in the magnetic field.
- pH-sensitive polymers are materials which swell/collapse when the pH of the surrounding media changes.
- Temperature-responsive polymers are materials which undergo changes upon temperature.
- Halochromic materials are commonly used materials that change their color as a result of changing acidity. One suggested application is for paints that can change color to indicate corrosion in the metal underneath them.
- Chromogenic systems change colour in response to electrical, optical or thermal changes. These include electrochromic materials, which change their colour or opacity on the application of a voltage (e.g. liquid crystal displays), thermochromic materials change in colour depending on their temperature, and photochromic materials, which change colour in response to light—for example, light sensitive sunglasses that darken when exposed to bright sunlight.
- Ferrofluid
- Photomechanical materials change shape under exposure to light.
- Self-healing materials have the intrinsic ability to repair damage due to normal usage, thus expanding the material's lifetime
- Dielectric elastomers (DEs) are smart material systems which produce large strains (up to 300%) under the influence of an external electric field.

The materials that would be most likely to be applicable for space and lunar purposes are the following: Self healing materials, photomechanical materials, shape memory alloys, and temperature responsive materials.

Self Healing Materials have the intrinsic ability to repair damage due to normal usage, thus expanding the material's lifetime. Initiation of cracks and other types of damage on a microscopic level has been shown to change thermal, electrical, and acoustical properties, and eventually lead to whole scale failure of the material. Usually, cracks are mended by hand, which is difficult because cracks are often hard to detect. A material (polymers, ceramics, etc.) that can intrinsically correct damage caused by normal usage could lower production costs of a number of different industrial processes through longer part lifetime, reduction of inefficiency over time caused by degradation, as well as prevent costs incurred by material failure.

A temperature-responsive polymer is a polymer which undergoes a physical change when external thermal stimuli are presented. The ability to undergo such changes under easily controlled conditions makes this class of polymers fall into the category of smart materials. These physical changes can be exploited for many analytical techniques, especially for separation chemistry. After numerous investigations of poly(N-isopropylacrylamide) (poly-NIPAAm), there was a sparked interest in the applications of this and many other stimuli-responsive polymers. There has been extensive research in the applications of intelligent polymers for use as stationary phases, extraction compounds, surface modifiers, drug delivery, and gene delivery.

A shape memory alloy is an alloy that "remembers" its original, cold-forged shape: returning the pre-deformed shape by heating. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems.

Shape memory alloys have applications in industries including medical and aerospace. Boeing, General Electric Aircraft Engines, Goodrich Corporation, NASA, and All Nippon Airways developed the Variable Geometry Chevron using shape memory alloy that reduces aircraft's engine noise.

Resources and Recycling

Near the South Pole, for example, some high crater rims are bathed in nearly constant sunshine. Sun-tracking solar arrays placed there would provide steady power and charge storage batteries to supply electricity during the brief periods of darkness.

An even more valuable resource may lie in the craters' depths. Spacecraft data suggest they could harbor hundreds of millions of metric tons of water ice, accumulated from billions of years of comet impacts. Using a simple electric heater, robot ice miners could free water for drinking and agriculture. Electrolysis could break it down further, supplying oxygen for breathing and hydrogen fuel for moon-to-Earth transportation.

Oxygen can still be pried out of lunar volcanic rock. Combining hydrogen gas brought from Earth with the mineral ilmenite, then heating the mixture to 1652 F, produces iron, titanium dioxide and water. Other chemical processes can also release oxygen from rocks, given enough heat and electricity. Lawrence Taylor, director of the Planetary Geosciences Institute at the University of Tennessee, is developing a magnetic "vacuum" hose, designed to suck lunar dirt into a dump truck or pipeline leading to an oxygen extraction plant.

At first, the power for these industrial processes would come from lightweight solar arrays. A compact nuclear reactor, tucked safely into a shallow crater away from living quarters, might be needed later.

To minimize the number of costly cargo shipments, the outpost will need efficient recycling technology. Wastewater, including urine, will be returned to a drinkable state using systems soon to be tested on the ISS. Carbon dioxide will be removed from the atmosphere using a catalytic scrubber that recovers some oxygen. But a lunar greenhouse will offer the biggest benefit. A few plants have been grown experimentally on the ISS, but never on a scale large enough to produce usable oxygen or food. The moon's steady polar sunlight would be ideal for greenhouse agriculture. Chris Brown, a plant biology professor at North Carolina State University, leads a group that has been experimenting with ways to grow lunar-ready white potatoes, soybeans and wheat. "Plants doing photosynthesis are fundamental to life on Earth," Brown says. "That same system should enable us to colonize other worlds."

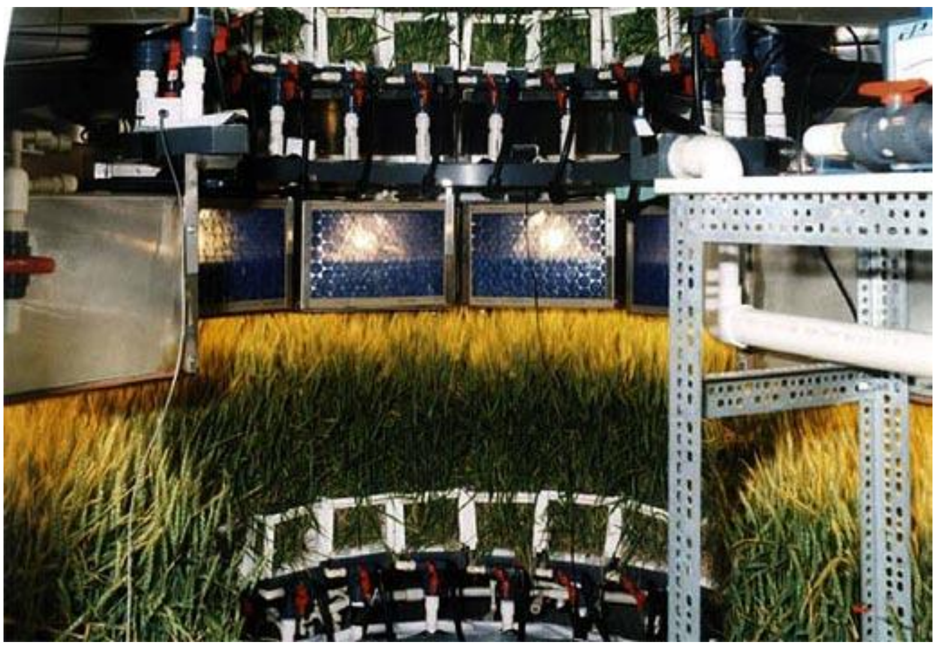


Figure 31 - Kennedy Space Center’s Growth of Wheat in Zero Gravity

Kennedy Space Center researchers have grown dwarf wheat in confined quarters to gauge the crop's ability to produce food, water and oxygen, and remove carbon dioxide during extended space travel.

IMPROVING TECHNOLOGIES

In an article written by Thomas Jones, former Astronaut, he wrote “How will residents cope with the hazards littering this airless, blasted body? Arriving crews will unload pressurized habitation modules, like those on the International Space Station (ISS), or perhaps inflate living spaces made of a tough, Kevlar-like fabric. For protection from cosmic rays and micrometeoroids, the pioneers could bury their habitats in trenches or heap lunar soil over them. With no atmosphere or magnetic field to shield them, as on Earth or Mars, lunar explorers will need to retreat to these shelters during a solar flares deadly shower of charged protons. A lucky find might be a lava cave to insulate the living quarters.

Exploring the surface will require a better spacesuit than the one I used as an astronaut to help assemble the ISS in 2001. That suit was too stiff at the waist for easy walking or bending, and its fiberglass torso and bulky life-support backpack made it top-heavy. The old Apollo suits wouldn't cut it, either: The gloves were clumsy, even painful after prolonged use, and the suits so stiff in the waist and knees that crews found it nearly impossible to reach for a rock.

Dean Eppler, a senior scientist at Science Applications International, a private firm in Houston, has spent hundreds of hours in prototype spacesuits, working out the kinks. "The moon suit is a work in progress," Eppler says, but "compared to Apollo's, it will have more flexibility for walking, bending and grabbing stuff off the ground, and be much more intuitive to work in." Lighter electronics and improved life-support systems should keep the weight between 150 and 200 pounds, just 25 to 35 pounds in lunar one-sixth gravity.

Future explorers will also need an improved version of the Apollo lunar rover, which two astronauts could drive about 40 miles before its silver-zinc batteries were exhausted. A new model might use solar rechargeable batteries, or electricity from hydrogen-oxygen fuel cells.

Both spacesuits and machines will have to cope with lunar dust: gritty, sharp-edged, and murder on seals and bearings. Engineers hope to use electromagnetic filters and shielding systems to prevent dust from working into critical components. Taylor is also developing a microwave-powered paving machine capable of reducing damage by turning lunar soil into hard landing pads or roads.

THE EFFECTS ON HUMANITY

Implementation of an outpost on the moon would have varying effects on humanity dependant on the success of its initial goals. The outpost has the possibility to enhance the field of alternative energy, answer questions about the history of the solar system, and spark an economic/technological boom. We will analyze the effects a lunar outpost and other projects associated with it could have on humanity. We will be working under the assumption that the goals set by the outpost are successful in practice and there are no unforeseen catastrophic accidents. Due to the increasing number of agencies and companies that wish to use space for their benefits we are witnessing the beginning of a great increase in the use of space. Through analyzing initial steps organizations plan to take or have taken we can get a better estimate on the effects a lunar colony will have on humanity.

A large piece of our economy and lives depends on the use of natural resources such as coal, oil, and natural gas to produce energy. There is a continuous search for a clean and renewable source of energy because those natural resources are not infinite and their emissions are harmful to the environment. Examining the graphs below and comparing the projected rate of the worlds per capita energy consumption and the worlds projected population growth we can see that all of the presently economically recoverable fossil fuels will be depleted by the mid 21^{st} century.

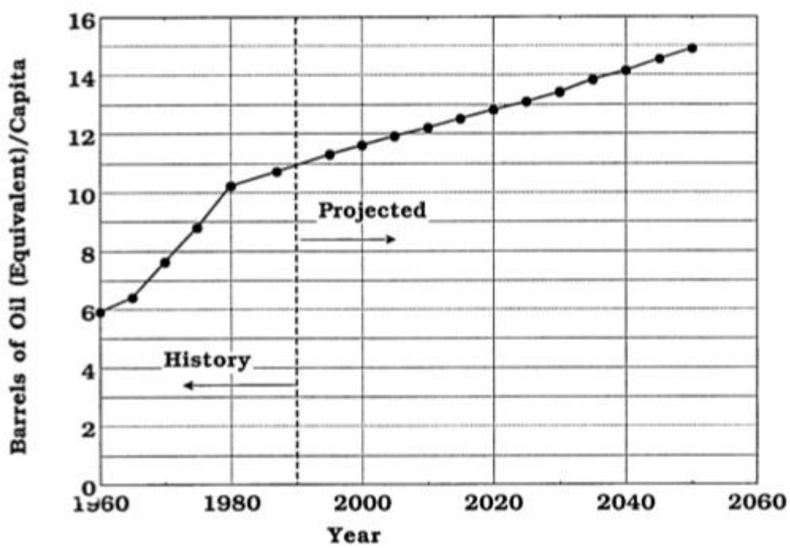


Figure 32 - The World's Energy Use per Capita (Projected in 1990)

The figure above is the world's per capita energy use measured in barrels of oil equivalent (BOE). BOE is based on the amount of energy released by burning one barrel of crude oil.

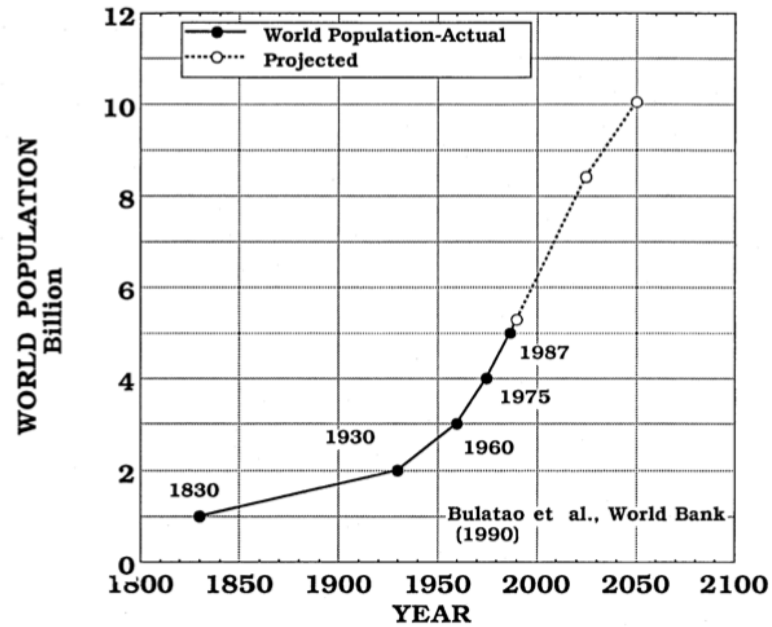


Figure 33 - World's Population Growth

The figure above depicts the world's population growth from 1930-1990 and then the World's projected population growth from 1990 to 2050.

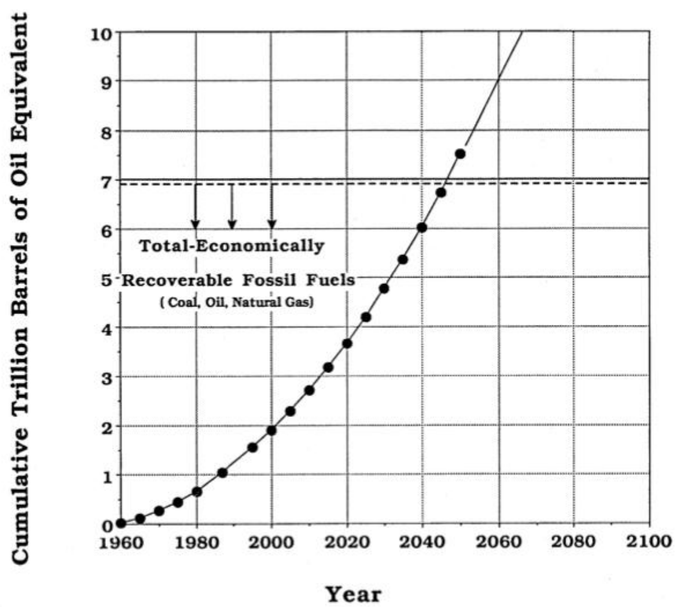


Figure 34 - Projected cumulative energy use

The figure above shows the projected cumulative energy use in trillion BOE calculated by multiplying population and energy use per capita. The dotted line represents the known reserves of economically recoverable fossil fuels. Even though these figures were projected in 1990 they are still relevant because even if the numbers are a few decades off it is still evident that an alternative renewable energy source needs to be used. In the period 1950-1980 nuclear fission showed promise. However there have been several disasters related to nuclear energy such as Three Mile Island, Chernobyl, and recently the complications with Japan's nuclear reactors. These disasters have created a public resistance to the long-term storage of nuclear reactive waster and the placement of nuclear fission reactors.

A lunar base could possibly contribute to the solution of the world's energy needs by two separate means. The first would be mining helium 3 for use as a nuclear reactant on earth and the second would be relaying solar power collected on the moon to the earth's surface. After analyzing lunar samples taken from Apollo missions in the 1970's and discovering that there is a project 1,000,000 metric ton on the moon. It is estimated that 25,000 tons of helium 3 could have satisfied the earth's electrical consumption in 1991. Estimating the initial cost of a ton of helium 3 at 1 billion dollars the energy content in helium 3 is equivalent to a barrel of oil priced at 7$. In 2010 a barrel of oil cost over 70 dollars showing a clear advantage for using helium 3. Helium 3 is not only economically viable but environmentally friendly as well. A deuterium helium 3 power plant would produce very little carbon emissions, have less than 1/10,000 the hazard potential of a fission reactor, and has no possible nuclear fatalities offsite in the event of the worst possible accident. A helium 3 helium 3 power plant has much of the benefits of a deuterium helium 3 plant but produces no radioactive waste, radiation damage or safety hazard after 30 years. Helium three is not an infinite solution but is much more economically and environmentally responsible source for energy than our current methods. Helium 3 power plants could be placed much closer to the demand for electricity which would reduce the cost of installing the power plant because less material to carry electricity to the demand would be required. However the downside to helium 3 is technology required to use it. We have not yet achieved a means of producing nuclear fusion and are even farther away from achieving it on a larger scale.

Another way a lunar outpost could provide energy to earth is the use of space solar power. Several companies have toyed with the idea of collecting solar power in space and beaming it to earth using wireless power transmission. Since 2009 there have been several developments in the commercial sector of space based solar power. Companies and agencies such as Space Energy, Inc., Solaren, PowerSat Corporation, and EADS astrium plan to execute some sort of space based solar power system within the next two decades. Space Energy Inc. is looking to harness solar power in space and sell it as a commodity on earth. The companies first step will be to make a model of space based solar power and launch it in low earth orbit. Once they have proven their method they plan to go full scale with their solar powered plan. The company believes that the prototype system they release will be the first one of its kind. Space Energy Inc. believes that the core science involved is proven but realize that improvements to launch capabilities, assembly of a full satellite in space, power transmission on this scale, managing space debris, managing solar winds, and commercial challenges as well. While Space Energy Inc. hasn't achieved their goal yet their business plan allows us to see some of the reasons this system isn't implemented (above) as well as see the potential good it can create.

They believe this technology has the power to aid in the independence from fossil fuels, bring power to rural locations, power to schools/hospitals, as well as provide the power needed for water purification in under developed regions. Examining the business model of Space energy Inc. we are able to see an example of how this technology could have an effect on society. Solaren Corp. has a very similar plan to Space Energy Inc. except Solaren Corp. already has a customer. Solaren Corp. and PG&E the combined natural gas and electric utility provider for central and northern California have agreed that by 2016 Solaren Corp should be supplying PG&E with 200 megawatt of electricity per year for a 15 year period. The more money invested in space based solar power the better chance for it to have a positive effect on society in the near future. PowerSat is another company in the space based solar powered market. This company takes a better look at the market drivers and explains the economical motivation behind space based solar power. According to the Energy Information Administration (EIA) consumption is projected to increase by 50% by 2030.

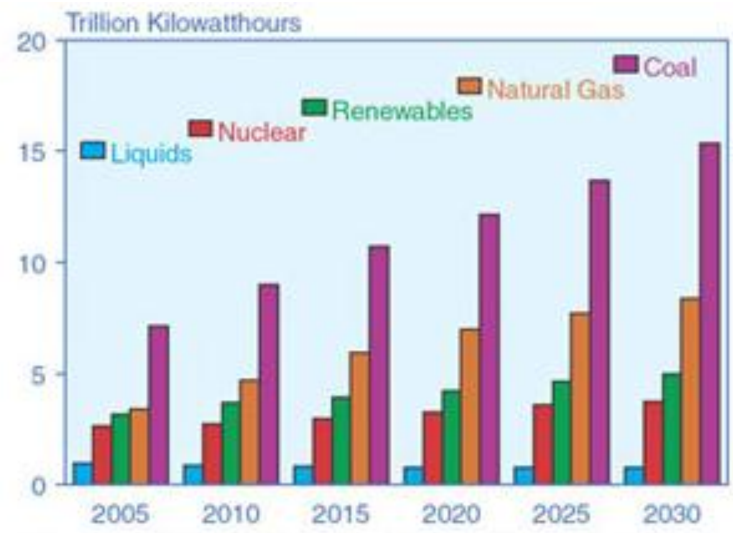


Figure 35 - World Electricity Generation by Fuel 2005-2030

Figure 35 above shows the projected consumption of electricity by the world from 2005-2030 according to the EIA. As well as projected consumption rising oil prices are projected to stay high. Coal use will increase with more people and create environmental concerns since CO2 emissions will also increase. Although renewable energy use is rising it does not compare with the consumption of coal and natural gas. Due to all the reasons above PowerSat believes it is economically beneficial to invest the start up capital and enter space for solar power.

Protecting the Earth from these near Earth objects is a major concern to scientists. Many believe that one of these objects will eventually hit the Earth and possibly cause global damage. Initially it was thought that we could just blow up these objects before they got too close to the Earth. More recently however, this approach does not seem practical. Blowing up an asteroid or meteorite would result in many smaller fragments to form. These smaller fragments could still possibly be dangerous. Also creating more space rock fragments would result in even more rocks to be tracked. A possible course of action for moving or deflecting a near Earth object would be what is called a kinetic impactor. A kinetic impactor is a small spaceship that would literally collide with the object, similarly to bumper cars, and transfer its momentum to the rock effectively deflecting it and changing the orbit. A major difficulty with this technique would be getting the spacecraft in the proper orbit so as to hit the near Earth object in the correct spot to deflect it away as opposed to deflecting it closer to the Earth. The success of an operation like this would be dependent on a few different factors including; the relative velocity between the spacecraft and the asteroid, the mass of the spacecraft and the composition and density of the asteroid. The impact could also fragment the asteroid especially if made of ice or rubble. A nuclear standoff explosion has also been discussed as a possible course of action to deflect a near Earth object. The space rock would be ejected back by the neutrons and x rays from the explosion hitting it. To use this method, scientists would need to know the size and composition of the object, knowledge that would likely be unknown unless a reconnaissance mission to the asteroid were conducted. A nuclear explosive may need to be created just for such an event, controlling the energy released and the percentage of energy in the x rays and neutrons. In most cases it is believed that the neutrons will cause more material to be ejected or vaporized from the object than the X rays will. Ideally very little material would be ejected from the space rock. A deflection operation must be initiated years in advance for it to be effective. A collision would result in a small change to the objects velocity that would accumulate into a large position change over time. It has been often discussed by scientists that the lead time should be about 10 years.

Establishing a lunar outpost could also positively impact the continued exploration and understanding of our solar system. Examining the lunar ice contained in the Shackleton Crater would allow scientists to look approximately 3.6 billion years into the past and find out more about our so the beginning of our solar system. Planned future missions similar to the most recent Discovery missions, “Kepler” and “Dawn,” could also add to that knowledge by studying the surface composition of 10 million year-old asteroids in the belt between Mars and Jupiter. Any of the deep space missions would require a significant amount of fuel that can lead to exponentially increase launch costs.

If an outpost is established on the Moon, it could be used as an effective launch pad due to its lower gravity and its lack of an atmosphere; both of these conditions mean less drag on the spaceship. The escape velocity is the speed at which the kinetic energy plus the gravitational potential energy of an object is zero. It is commonly described as the speed needed to "break free" from a gravitational field. The term escape velocity is actually a misnomer, as the concept refers to a scalar speed that is independent of direction. In practice the escape velocity sets the bar for any rocket aiming to bring a satellite beyond earth orbit. It gives a minimum “delta-v” budget (change in velocity) for rockets when no benefit can be obtained from the speeds of other bodies, for example on interplanetary missions where a gravitational slingshot may be applied.

The Shackelton Energy Company has devised a more extreme view of using the moon as a launching pad. It is believed by some in the scientific community that lunar ice can be harvested and broken down into its base components oxygen and hydrogen. These components can be than be converted to rocket fuel. To harvest this water, scientists have simulated lunar soil in vacuum and used microwaves to heat it up. At only -50ºC the water vaporized (due to presence of the vacuum) and was able to be collected using condensation. The Shackleton Energy Company (Del Valle, Texas) led by CEO William Stone, has recently begun investigating the harvest of lunar ice. His plan, which coincides with the water collection procedure described above, outlines a future timeline for the now-feasible mission. Stone's company idealizes to build fueling stations for space vehicles in low-earth orbit. Using ice found in the polar craters, the team would turn the filtered water into different types of fuel. Since the Moon's gravity is much less than of that on Earth, the cost to launch this fuel into LEO is about 93 – 95 % cheaper. If this mission succeeds Shackleton Energy Co. will have opened the doors to the expansion of space travel. Using this technology, rockets would only have to carry enough fuel for the initial trip into space, significantly lowering the cost of a launch from Earth. Within four years Stone's group plans to launch a robotic scouting mission to each of the poles looking for craters that contain the most ice. Granted the missions are a success, SEC hopes to land its initial crew to begin the mining in the next 15 years.

A lunar outpost in the long term could cause humans to experiment with manipulating DNA to better prepare humans for space travel. Inheritable characteristics in humans are passed down through generations via DNA. DNA is a nucleic acid that contains the genetic instructions used in the development and functioning of a human being. The segments of DNA that carry these instructions or genetic information are called genes. Scientists have recently learned how to mix and match characteristics among this genetic code which is known as genetic engineering.

There are two types of genetic engineering currently proposed called somatic engineering and germline engineering. Somatic engineering involves the manipulation of somatic cells that are the cells that make up organs, skin, bones, and tissues. In this process also known as gene therapy, healthy genes are placed into a non-pathogenic virus that is then inserted into the body. From here the virus would replicate and insert itself into the DNA. The healthy gene could also be put in a large package as an add-on to one of the 23 chromosomes or as a 24^{th} chromosome. Somatic engineering is non-inheritable, meaning that any change to the genome would not be passed down through generations. Germline engineering is inheritable and will be passed down through generations. This process requires the modification cells that are part of the germline. This process is used in the modification of female eggs, sperm cells, or early embryos. Germline engineering is the most controversial type of genetic engineering as it requires the genes of an egg or embryo to be modified. The main opposition to this procedure believes that the child should be able to have the choice of whether or not they want to be altered.

Stem cell research and organ growing is another realm of genetic engineering. The human need for new organs is constant. Every day thousands of people die while waiting for a new organ. In 1997 alone, less than 10% of the 40,000 patients in the US needing a heart got one. The statistics are more or less the same for those needing new skin, liver or kidneys. With organ growing as a possibility, it would create a nearly endless supply of organs for those who need them. Also because these organs would be grown from a cell of the patient, the risk of rejection would be eliminated. There are three ways an organ can be grown; internally, externally, or in a host animal.

Internal organ growing involves implanting biodegradable polymers to act as a shell like structure or mold for the organ to grow in inside of the patient. Stem cells are then injected into the mold and replicate within the wound site. The mold naturally breaks down and is ejected as waste by the body.

The external growing process also uses molds of structures in the shape of the required organ. The patient's own progenitor cells are identified and separated through a biopsy and placed in this scaffold to regenerate and grow into the needed organ. After maturing into a full sized organ, it is implanted into the patient. This has been done successfully with a bladder where the implanted bladder functioned just as well as a perfectly healthy bladder.

With the field of genetic engineering rapidly growing, it is only a matter of time before humans can be genetically altered to be more efficient in space. The human body consists of microbes that help with things such as breaking down food and keeping our immune system in check. These microbes theoretically could be modified to help astronauts even more. Different synthetic microbes to be considered would be ones to help astronauts absorb nutrients from food more efficiently or microbes to increase defenses against radiation. According to genomics engineer J. Craig Venter, "The microbe Deinococcus radiodurans can survive radiation doses 7,000 times higher than those that would kill a human. The bug can reassemble its DNA after its genetic material gets blasted apart by powerful radiation. If scientists can figure out how to incorporate such super-charged DNA repair genes into the human genome, astronauts won't have to worry so much about the damaging cosmic rays hurtling through space." This would allow for extended stays in space and even colonization.

Unfortunately through all of the good that could come from this, there is also bad. The threat of bioterrorism is a real concern. Using the same techniques discussed above, terrorists could develop new viruses and diseases killing many people. There is also the issue of human testing. In order to know for certain if the alterations of the human body will work, humans will have to be tested and in turn be subject to things such as high doses of radiation. While Venter and others are on the right track to human genetic engineering there is still a long way to go before successful "custom-built" humans inhabit the moon and space.

The development of futuristic satellites could further the exploration and conquest of space as well as improve life here on Earth. New technological advancements could lead to earlier and more precise predictions. These improved weather satellites would be able to scan the Earth faster than those currently in use and track tropical storms and hurricanes. By analyzing the constant incoming infrared radiation these satellites will be able to provide meteorologists with extremely accurate air and water temperatures.

Futuristic satellites could also be used for militaristic purposes. The US military has already begun researching weaponized satellites that could be used to shoot down an enemy missile heading toward our territory or an intrusive spy satellite recording our operations. Of course, we could also use these high-tech satellites to do the spying ourselves. Nanosatellites (between 1 and 10 kg) and picosatellites (between .1 and 1 kg) are already being developed and could be used for future reconnaissance missions. These observation satellites could also be used for the Earth's protection in the detection (and possible destruction) of objects that might cross the path of Earth's orbit. Deep space telescopes similar to the Hubble could be installed to continue the visual exploration of the closer galaxies.

Any future developments could also benefit our long-distance communications. GPS-based systems such as navigation would become faster and more reliable. Cellular reception would improve and possible be expanded to be able to reach other countries and continents. The communication with space vehicles and the International Space Station would improve. We could use the improved transmission status to control vehicles or probes on the Moon and other planets. For example, the current delay between Earth and Mars is too large to successfully control a delicate maneuver or procedure. Using relay satellites with low delays we would be able to explore foreign terrain in greater depth.

With technology improving at an exponential rate, the implementation of new satellites with futuristic capabilities will undoubtedly change the way we live. We can count on new ideas and developments to significantly influence the way life on Earth, and in space, is conducted.

The benefits of conducting experimental research on the moon, or low-gravity conditions in general, are not limited to the future missions we could perform. Many of today's popular innovations came from development and testing in space. Products like satellite dishes, scratch-resistant lenses, home security systems, solar power, sewage and water treatment systems, and medical imaging have all been created for some original space purpose and found useful application on Earth. The technology to manufacture these products is also rapidly increasing allowing us to think that there are even more important discoveries to come. The recent discovery of water on the Moon leading to the renewed interest in space exploration is sure to intrigue young, intelligent minds to enter the field. With increasing commercialization and private businesses entering the mix of space development, competition between companies will act as a catalyst to spark a new wave of innovations.

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