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Humanity and Space

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HUMANITY AND SPACE

Interactive Qualifying Project Report completed in partial fulfillment

of the Bachelor of Science degree at

Worcester Polytechnic Institute, Worcester, MA

Submitted to:

Professor Mayer Humi

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Ben Mininberg ________________________

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Date Submitted

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Advisor Signature

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Abstract

All throughout history, space has been an enabler and driving force of the advancement of technology, ranging from the earliest navigation systems to modern microelectronics. We have analyzed the technology behind and benefits of establishing a permanent human presence on the Moon, and we have presented our findings in a way that is understandable to laypeople in order to ease the dissemination of the scientific, commercial, and societal importance of continued space research and development.

Executive Summary

Since ancient times, space has served humanity in a variety of ways. For thousands of years, the night sky was the best way to track the passage of time through lunar calendars. The first farmers used the cycles of the moon to determine when they should plant or harvest their crops. It was also used extensively as a way of predicting global or personal events around the world; indeed, the entire field of astronomy grew out of astrology, which originally used the celestial bodies to predict events.

In recent times, we have come up with a vast number of uses for space, such as communications systems, Global Positioning Systems, and spy satellites. Many modern technologies have their roots in the space program; the first serious miniaturization of electronics was done to get man on the Moon.

As the United States debates whether or not to bother returning to the Moon, it will serve us well to understand why we should return. The Moon contains vast quantities of Helium-3, which is a key component to the process of nuclear fusion, which would effectively solve the world's energy crisis. Lunar telescopes could serve us in a variety of ways: they could be used to forecast space weather, whose electromagnetic storms have and continue to severely impact life on Earth; they could track known near-Earth objects and discover new ones, whose potential impact with Earth would be absolutely devastating to the survival of mankind; and they could be used to push the envelope of human understanding in the origins of the universe and the search for extraterrestrial life. Space tourism is also a very valid commercial reason for returning to space, as the current global tourism industry generates over a trillion dollars of revenue annually. The Moon is also an extremely good launching point for new satellites or deep-space vehicles, as the substantially lower gravity and lack of atmosphere make rocket size requirements for launch vehicles substantially lower.

In order to fulfill all these desirable goals, we must return to and colonize the Moon. To do so, we have analyzed NASA's current plans and evaluated several of the challenges along the way. The lift vehicles of the constellation program, the Ares I and the Ares V, are currently being developed, with the successful launch of the Ares I-X prototype occurring this past October. The Altair Lander vehicle and Orion Orbiter vehicle are still in very early design and prototyping. Several desirable locations for the first lunar colony are discussed and evaluated, and Mount Malapert, on the Moon's South Pole, is selected as the most desirable location. We have evaluated the issues of survivability on the Moon, and have determined that this location is very likely to have large quantities of mineable water ice, which is both necessary in its base form and as an atmospheric component. The lunar regolith (surface material) is also rich in a wide variety of other useful materials, such as titanium, which would serve as construction material, reducing the amount of material and equipment that would need to be taken from Earth. The risks and safety issues that arise in such an environment are also analyzed, with several solutions proposed, such as using the lunar regolith as radiation and micrometeoroid shielding.

The societal impacts of returning to the Moon are also evaluated. Several visions of the future are discussed, including the possibilities of deeper-space colonization, such as the asteroid belt and the moons of Saturn.

Returning to the Moon and establishing a permanent human presence is an important goal for the first half of this century, as there are a wide variety of extremely desirable goals that it can fulfill for us, both scientifically-driven and commercially-driven.

Introduction

We have analyzed the technology involved in humanity's return to the Moon, as well as the challenges presented throughout the process of establishing a permanent settlement. Additionally, we have investigated the potential scientific, commercial, and societal benefits that would result from such an effort. Along the way, we have analyzed several of the difficulties such an endeavor would encounter, and have provided solutions to these challenges where possible. Lastly, we have provided several views of the possible future of humanity after colonizing the Moon.

Alex Kindle

Alex Kindle's interest in space was first fostered by the works of Orson Scott Card and Isaac Asimov, both of whom are largely responsible for his current interest in technology and robotics. He is a Robotics Engineering/Electrical and Computer Engineering double major, so advances in space exploration are extremely relevant to his studies. During the course of this project, his exposure to the past and current projects at NASA has piqued his interest in the field of space robotics, and he aspires to be a robotics engineer for NASA.

Ben Mininberg

Ben Mininberg is a Biology Major in the Class of 2011 for whom space technology, both real and fictitious, has always sparked the imagination. As a Biology major with a strong interest in the humanities, an IQP that looks at both the technology behind and implications of an expanded space effort was a good technically-inclined bridge between his varying interests. His career goals include being able to bring a strong writing background to the scientific fields, and this project proved an excellent source of practice in taking complex and technical details and synthesizing a project that is accessible to non-technical people in an effort to help people understand why an expanded space effort is crucial for the future of humanity.

1. A Brief History of Mankind's Space Ambitions

1.1 Ancient Civilizations

Humans appear to have been fascinated with the sky and stars for as long as recorded history and tradition exists. Ancient Judaism and the Old Testament of the Bible are full of examples of humanity's fixation on the stars, including the story of the Tower of Babel, in which humanity creates a tower tall enough for them to reach the heavens. Yahweh himself is described as residing in the heavens above, observing Israel below on Earth. Something had to motivate ancient peoples to look up at the sky, be it a practical reason or something more fantastical.

The Hebrew people found practical use in studying the sky as the basis for their calendar. The Hebrew Calendar is a fixed lunisolar calendar using a seven day week with twelve 29 or 30 day months and an extra corrective month added in every two or three years. The importance of a calendar system is obvious for an ancient civilization, and there is none more accessible or trackable than one based on the night sky. Having an accurate method of keeping track of time led to the development of tradition and religious sacred times, but all of these things owe their existence to agriculturally important times. Without some method of seasonal time keeping, agriculture suffers, and food supplies as a result. Barley was a crucial crop for the ancient Jews, and as such, their calendar is able to keep track of the time to plant barley as well as harvest it.

History provides a seemingly unlimited number of examples of humanity's fixation with the sky above them, a fascination for which there must be a common source. Realizing the movement or changes in the night sky could be followed regularly allowed many civilizations to keep track of time and the seasons, leading to tangible benefits like improved knowledge about the harvest time of crops. Finding a practical use for the mysterious bodies in the night sky would lead to a greater appreciation of the stars and space above, and a developing interest in what is actually up there.

One of the oldest uses of the night sky is the practice of Astrology, which is based on the idea that by looking above, we can understand things around us. With earliest written records of Astrology dating back to around 3000 BC, it is one of the oldest uses of the night sky. Up until the 1800s, Astrology and Astronomy were largely indistinguishable; the science of Astronomy developed out of Astrological desire, and it wasn't until modern times that the two were decidedly viewed as separate fields. This desire to explain everyday life by studying the sky parallels many other religions at the time over a variety of cultures.

Other ancient civilizations first looked up for several reasons. They used the night sky to understand the passage of time and the seasons, and they treated daytime events as religious or mythical phenomena. The very first calendars used lunar months, in which one new moon to the next constituted a month. When combined with the positions of the stars, farmers could predict changes of season, and could time the planting and harvest of their crops more effectively. Both ancient Greece and ancient Egypt based their civil calendars off of solar and lunar positions. In order to better identify star positions, the Greeks came up with about 80 constellations in their night sky, which were predominantly named after key figures in ancient Greek mythology, such as Hercules, Andromeda, and Ursa Major.

Ancient China subdivided the night sky into three Enclosures, 28 Mansions, and over 280 constellations. Unlike the Greek constellations, Chinese constellations were frequently named and imaged after commonplace items, such as the Plough. The Chinese calendar, while also being a lunar and solar calendar, was exceptionally precise; beyond using it to track down-to-earth things like harvest and planting times, they also used it to track heavenly events, such as solar and lunar eclipses, which, in the case of solar eclipses, were tracked in order to be prepared with sacrifices held in fear of the blacking out of the sky, and in hopes that sunlight would return again. Likewise, the ancient Chinese tracked as many earth-bound and astronomical events as they could, in order to better prepare themselves and anticipate their future.

In ancient Greece, astronomy gave birth to the Astrolabe, which allowed sailors to navigate the oceans by using the positions of the stars. The ability to plot position dependent upon celestial bodies evolved over the centuries, and is ultimately responsible for all pre-industrial oceanic navigation. To plot one's position using celestial bodies, one would measure the angle between the object (frequently the sun or moon; there are numerous stars that can be used as well), and by knowing the object's position above the Earth at that day and time (which would be predetermined and written in a nautical almanac), one could plot a circle around that point of possible current locations; by doing this for multiple bodies, any intersection point would be a valid location. These locations are typically thousands of miles apart and can be notably different (such as the sun being to the left or right of the moon, or one point being on land), so current nautical position could be determined with just two reference locations.

To quote Sir George Cornewall Lewis on the subject of astronomy, "The sun exercises so decisive and conspicuous an influence upon the actions of men during every hour of their life, that all nations, from their earliest existence, must have found it necessary to watch his movement; and from their observations to form certain measures of time." Since people were so dependent on the sun's light for even the most basic daily activities, it only made sense to keep track of the sun's actions and behavior in order to maximize useful day time. Once it was realized that the lengthening and shortening of the days is cyclic, it followed to observe other celestial bodies, such as the patterns of stars in the night sky, for patterns of their own; hence the widespread usage of constellations whose patterns were well-known to their observers.

1.2 Recent United States History

Thousands of years later, he United States National Space Policy laid out the goals and regulations of a US-managed world-wide Outer Space. In the introductory section, the United States' dominance over and management of space is asserted due to the US's leading position in space exploration and technological development over the past 50 years. The document contains an acknowledgement of the increasing importance of a space presence in the modern world, as well as an explanation of the US's role in managing the use of space in ways beneficial to the United States and other friendly nations, as well as entrepreneurs and private business.

The first section of guidelines outlines the Principles of US Space Policy. The guidelines contain an emphasis on maintaining the neutrality of space, with the second clause rejecting any claims of sovereignty over a space body that would infringe on the US’s ability to conduct its affairs in space. Along with maintaining stellar neutrality, the Principles condemn interference between space operations by different nations. There is also a priority placed on preserving the United States’ declared right to conduct their own affairs in space, in that the US reserves the right to take action against other nations’ space operations if they are interfering with the United States’ ability to operate in space, in the name of national security:

‘…the United States will: preserve its rights, capabilities, and freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; take those actions necessary to protect its space capabilities; respond to interference; and deny, if necessary, adversaries the use of space capabilities hostile to U.S. national interests;’

The next section contains the Policy Goals of US Space Policy. The first and most important goal is that the United States will operate in space to increase the nation’s space leadership and ‘further U.S. national security, homeland security, and foreign policy objectives;’. The Goals section also states that the US plans to have unhindered freedom to operate in space, both in the name of forwarding technological advancements as well as encouraging foreign cooperation with friendly nations as long as there is no risk to US national security.

Sections 4 and 5 contain guidelines for how the US will operate in relation to space, both in a general sense and in ensuring national security. These guidelines include crucial aspects of development in labor and technology. The development of ‘Space Professionals’ held to government departmental standards and a strengthening of US interagency cooperation is intended to lead to a higher standard of excellence and expertise, able to accomplish the broad goals of US Space-based technology advancement also outlined here. The National Security Space Guidelines are the longest section of the Policy, containing US goals in regards to maintaining US use of space for intelligence gathering. The Secretary of Defense is given the responsibility to maintain the US ability to operate in space to defend its interests as well as establishing a missile defense system and early warning intelligence gathering systems. The Director of National Intelligence is tasked with developing and maintain space-based intelligence gathering systems including those that: ‘Provide a robust foreign space intelligence collection and analysis capability that provides timely information and data to support national and homeland security;’. Section 8 contains the guideline on International Cooperation, in that the US will only operate with allow the operation of space operations by those nations deemed friendly to the United States and its goals. The final section, Section 13, outlines the Secretary of Defense and Director of National Intelligence’s task to manage and protect US space operations, including the use of space-based photoreconnaissance, something currently in use today and now crucial to US foreign policy and decision making.

The next two sections are on Civil and Commercial Guidelines for US Space operations. These sections outline what departments will be responsible for encouraging both basic scientific exploration and commercial development of space. The National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration under the Secretary of Commerce, the Secretary of the Interior through the Director of US Geological Survey, and the Secretary of Commerce are tasked with establishing both scientific and civil space exploration as well as a dominant US commercial presence in Space. Environmental monitoring systems and other 'mature research and development capabilities' are intended to enhance scientific understanding. There is also a guideline to enhance US commercial space usage, including plans to 'Continue to include and increase U.S. private sector participation in the design and development of United States Government space systems and infrastructures'. Section 12 contains a clause on the case-by-case determination of data, systems, and technological exports.

The next three sections, 9, 10, and 11, deal with technological concerns of the US in space. The US reserves the right to use nuclear power in space-based operations, with the specifics of each use analyzed by the Secretary of Energy and Interagency Nuclear Safety Reviews Panels. Guidelines are also established for the development of private operations using nuclear power, and the checks the US government will perform on such operations. The last two sections deal with currently crucial concerns for any and all space based operations, in the preservation of the Radio Frequency Spectrum and management of Orbital Debris. Any and all space operations are reliant on radio communications, and the US plans to protect US global access to the radio spectrum, including protecting its interests against harmful radio interference. Orbital debris has become an increasing cause for concern, as the concentration of hazardous debris increases constantly, and an increased space presence only has the potential to make orbital debris an even more serious threat. The US Government Orbital Debris Mitigation Standard Practices are in place to try and minimize these potential problems, and the US also tasks itself with taking a leadership role in encouraging the international body to follow similar guidelines and policies.

The US National Space Policy is a strong-voiced document designed to protect US interests first and foremost. The Policy contains a commitment to improve technology and increase the United States space presence, and also allows the US to take actions deemed necessary to protect its interests in space. There is explicitly and conspicuously no content dealing with maintaining a weapon-free space, which could allude to a US reservation of its rights to take any and all action necessary to protect its interests.

One of the most significant issues facing humanity in space is the potential militarization of space. The potential for satellite-based weaponry, lunar warfare, and interstellar battles has been the focus of countless sci-fi novels, and operating peacefully in space is of extreme importance. Currently, under the UN Treaties and Principles on Outer Space, nuclear weaponry and weapons of mass destruction are flatly banned from space, as are all forms of territorial claims, treating non-terrestrial areas in a similar manner to international waters. As it stands right now, all space-faring nations have signed and ratified the treaty; unfortunately, conventional weapons are not mentioned at all. The Moon Treaty of 1979 and the Space Preservation Treaty were intended to more thoroughly ban militarization of space, but both have been met with extremely limited support; neither is supported in any space-faring nation.

Unfortunately, the United States National Space Policy seems to flatly ignore the importance of keeping space demilitarized; while it never directly states the intent to arm space, nearly every section references the importance of space to national security at least once. It never directly states that the U.S. wishes to arm space, but it comes uncomfortably close to it:

> "Develop and deploy space capabilities that sustain U.S. advantage and support defense and intelligence transformation; and employ appropriate planning, programming, and budgeting activities, organizational arrangements, and strategies that result in an operational force structure and optimized space capabilities that support the national and homeland security"

It doesn't directly state the intent to arm space, but it is certainly implied. This desire to arm space is backed by the actions of the United States in the U.N.; in a recent vote on negotiations of a space weapons ban, the vote was 160 to 1–the United States was the only country in the U.N. against such negotiations.

In response to our not-so-subtle military ambitions, other nations are advancing military purposes. In January of 2007, China conducted a successful anti-satellite weapon test, in spite of having claimed frequently and recently that they were not developing anti-satellite weapons systems; many people viewed this demonstration as a response to the then-recent United States National Space Policy changes, which contained the militaristic vocabulary in question.

Indeed, anti-satellite weapons systems aren't exceptionally new; in the 1980s, both the United States and the then-USSR demonstrated successful ASAT systems, and the United States again demonstrated an anti-satellite weapon launch in February of 2008, where a malfunctioning spy satellite was shot down with a traditional anti-ballistic missile. Naturally, this demonstration was widely viewed as a response to China's ASAT demonstration of the previous year, as the $100 million interception was not justified by the satellite's expected crash course, which placed the risk to a single human life below one percent.

The terrifying potential for a space-based arms race exists, and looms like a dark cloud over future space-based research and ambitions, and the United States' current defiance of both the Outer Space Treaty and the wishes of every other nation in the United Nations bodes extremely poorly for a peaceful future in space.

The Strategic Defense Initiative was proposed by President Reagan in 1983 as a plan to use a comprehensive network of systems to defend the United States against enemy nuclear ballistic missiles. The program was to include both ground and space-based systems that used a variety of detection and kill techniques to intercept ballistic missiles on their way to the United States and destroy them or prevent them from reaching their target.

The Ground-Based aspects of SDI were comprised of both conventional projectile weapon systems and some Directed-Energy Weapon systems. The goal of these systems was to intercept a ballistic missile and either disable it by destroying its guidance system or directly causing the warhead to detonate prematurely and destroy the missile. The Extended Range Interceptor was a ground-based missile that could use radar-homing to track and intercept a target. The Homing Overlay Experiment was a system designed to increase the accuracy of a ground-based intercept missile by increasing the effective cross-section of a projectile designed to intercept a missile. The HOE was effectively a deployable metal web that would intercept a warhead and cause it to detonate, a potentially easier task than hitting an incoming ballistic missile with another missile to destroy it.

The Directed Energy Weapon systems relied on a much different process to intercept ballistic missiles. DEWs relied on pinpoint accurate firing solutions to fire a direct attack at a target, rather than deploying a self-guided intercept vehicle. The DEWs included X-Ray lasers, Chemical lasers, and hypervelocity rail-gun technology. Most of these technologies were ideally suited for space-deployment on defense satellite platforms, as being in space provided a closer proximity to the target, and in the case of lasers the atmosphere-free or low-atmosphere environment allowed for more powerful function. The laser systems were extremely difficult to operate accurately. In the case of the X-ray laser, this targeting problem was to be overcome by attrition in the form of a blanket laser defense activated in proximity to targets. Experiments were also performed on the idea of using satellite-based mirrors to redirect ground-fired lasers at a target. Hypervelocity electric rail guns were also tested as kinetic kill weapons. Rail guns rely on using massive amperage and voltage to drive a conductive projectile down a barrel through magnetic motivation. Due to the incredible velocity of the projectile, only a very small projectile is required to deal massive damage, but there are many limitations on the feasibility of such a weapon due to the massive fatigue on the barrel system as well as the problem of keeping the projectile viable at such incredible velocities.

The most successful of the SDI technologies was the space-based Brilliant Pebbles system. The Brilliant Pebbles system deployed satellite launched kinetic kill missiles to intercept ballistic missiles in space. Brilliant Pebbles relied on advanced tracking technologies and a massive number of intercept missiles to succeed where other specific targeted space-based intercept vehicles failed. Brilliant Pebbles combined projectile attrition with complex sensor and navigation systems to ensure a high chance of intercept with an enemy ballistic missile as it was entering space.

In 1983, President Ronald Reagan proposed the Strategic Defense Initiative, whose purpose was to develop ground and space-based systems to comprehensively defend the United States from a large-scale ballistic missile attack, in an attempt to shift cold war tensions away from an offensive policy of mutually-assured destruction to a more strategic defense. Although the SDI system was not completed before the end of the Cold War, the project has since changed names and purposes, becoming the Ballistic Missile Defense Organization in 1993, and then the Missile Defense Agency in 2002. These changes also pointed to a shift in purpose away from a country-wide large-scale ballistic attack prevention system to a theatre-wide missile defense system. Regardless of the program's name, it has given the United States a massive lead in space technology and defense systems, with over $100 billion being invested in research and development over the past 25 years.

Possibly the most important development to come out of the SDI came from the program's sensory systems developments, which covered ultraviolet, infrared, visible light, RADAR, and LIDAR (Laser Image Detection And Ranging) sensing technologies, whose research culminated in the Deep Space Program Science Experiment, or Clementine, which was a satellite constructed under the BMDO and launched in 1994 to test various sensors and components under extended space exposure, while making scientific observations of the moon and near earth asteroid Geographos. The Clementine satellite was launched on January 25th, 1994 and weighed 227 kilograms. On board was a charged particle telescope, an ultraviolet/visible light camera, a near-infrared CCD camera, a LIDAR system, and a high-resolution camera. Unfortunately, a malfunction in one of the satellite's attitude controlling thrusters en route to Geographos put the satellite in an 80 RPM spin, rendering it unable to complete any of the experiments on Geographos. In spite of this, the wide array of observations of the moon resulted in one of the most important lunar discoveries ever: the potential existence of polar ice in deep craters.

The moon's axis of rotation is a mere 1.3 degrees off perpendicular relative to the ecliptic plane, meaning craters near the poles are permanently in the shade. As a result, their interiors never get above a balmy 100 Kelvin, which would trap any and all water (as well as some other substances, such as methane) as ice. Clementine's Bistatic Radar Experiment, which was improvised during the mission, was the first attempt to verify the presence of ice in these polar craters. S-band radio signals (2.273 GHz) were directed into the craters, and then a terrestrial antenna in the Deep Space Network picked up the reflected signal. Frozen water is substantially more reflective to S-band signals than typical moon rock, so through signal analysis it was possible to determine the presence or absence of water ice. Based on the results of this experiment, there is hypothesized to be a deposit of frozen material between 60,000 and 120,000 cubic meters. However, when studies were performed using the Arecibo radio telescope in a similar fashion, such reflections were found in regions that were not permanently shadowed, casting doubt on the possibility of polar ice.

In addition to the improvised Bistatic Radar Experiment, the planned experiments yielded fantastic data. The LIDAR system plotted an altimetric map of the moon, and the high-resolution camera fully photographed the entire lunar surface.

In 1998, the Lunar Prospector mission attempted to confirm the existence of polar ice deposits. The mission's Neutron Spectrometer was designed to detect hydrogen on the moon, particularly at the poles. It did this by using two canisters, each containing Helium-3 and an energy counter; any neutrons colliding with the Helium-3 atoms would give off a distinct energy signature, which would then be detected and recorded. By wrapping one canister in cadmium and the other in tin, it was possible to detect the presence of hydrogen. The cadmium-wrapped canister would block thermal neutrons, while the tin-wrapped canister would not. Thermal neutrons are cosmic ray generated neutrons which have lost substantial amounts of energy in collisions with hydrogen atoms. By comparing the difference in detected energy between the tin canister and the cadmium canister, it was possible to estimate quantities of hydrogen on the moon. Based on data from the Neutron Spectrometer, it is estimated that there is as much as 260 million gallons of water on the moon.

In one last-ditch effort to verify the existence of lunar ice, the Lunar Prospector was crashed into one of the permanently shadowed craters, in an attempt to eject water particles into visible range of a wide array of telescopes. Unfortunately, no water was detected from the collision, but the estimated chance of detection if there had been ice present in the crater was less than 10%, so the results were not conclusive.

Thanks to the Strategic Defense Initiative, we now have reason to believe that there is water on the moon, and if there is water, it is substantially more feasible to establish a permanent manned facility on the surface of the moon.

2. Lunar Colony Logistics

2.1 The Issue of Water

In the event that there is extremely limited or no pre-existing water on the moon, we will have to come up with a way of synthesizing it there, due to the prohibitively high expense of exporting it from the Earth. In terms of parts per million, the lunar regolith (the top several meters of dirt) is roughly 420,000 PPM oxygen; over 40%. This oxygen is locked up in lunar minerals, which are comprised primarily of metal oxides bonded with silicon, and all of these minerals contain oxygen. For example, the lunar mineral Anorthite contains Aluminum, Calcium, Silicon, and Oxygen, in the mineral $CaAl_2Si_2O_8$, which could be smelted into pure Aluminum, Calcium, Silicon, and Oxygen. By smelting the various minerals on the moon, an abundant supply of many of life's necessities (for both human survival and commercial purposes) can be obtained, including Oxygen, Silicon, Aluminum, Iron, Calcium, Sodium, Potassium, Magnesium, and Titanium, which are all found in quantities greater than 1% in the lunar regolith, with all except Potassium and Sodium being at least as abundant as they are on Earth, if not more so.

Unfortunately, the lunar regolith is very poor in three very important elements: Hydrogen, Nitrogen, and Carbon. Hydrogen exists in quantities as low as 50 PPM, and Carbon and Nitrogen are about 100 PPM. The only saving grace to this is that these PPMs are by mass, and Hydrogen is the lightest element, so while still rather scarce on the moon, there is still a usable quantity of Hydrogen. Additionally, unusually high densities of Hydrogen were found by the Lunar Prospector mission in the poles, which may either be direct sources of water, or at least of hydrogen. In a mining operation for Helium-3, which is one of the strongest reasons for colonizing the moon, 100 million tons of regolith would need to be processed for one ton of Helium-3. Provided the regolith was processed in an efficient manner, this would net at least 40 million tons of oxygen, and a mere 500 tons of Hydrogen. Hydrogen is about 11% of water (by mass) and this Hydrogen could then be processed into about 4500 tons of water, which is about a million gallons. Assuming a lunar regolith mining operation could be robotically managed; enough of the basic requirements for human life could be synthesized on the moon's surface, producing a vast supply of oxygen, water, nitrogen, and various metals.

2.2 How to Get There

The Constellation Program is NASA's current human spaceflight program, with an emphasis on developing technologies for extended missions to both the moon and eventually Mars. One of the primary goals of the Constellation Project is the development of the next generation of United States human-piloted spacecraft, designed especially for a renewed and expanded human presence on the moon. Two purpose-made craft are in the works, the Orion spacecraft system, built by Lockheed Martin, and the Altair Lander, expected to be carried by the in development Ares series of Launch Vehicles.

Technologically, the Orion system is a combination of previously used and proven systems from a variety of NASA missions. The Orion will include 'autodock' systems like that of the Russian Progress spacecraft, and an advanced cockpit control system derived from the Boeing 787 'glass cockpit'. The actual spacecraft will be constructed from the aluminum lithium (Al/Li) alloy currently used on the shuttle's external tank, and the Delta IV and Atlas V rockets. The main propulsion will be provided by Aerojet AJ-10 rocket engine used on the second stage of the Delta II rocket, using hypergolic fuels, with the maneuvering rocket system resembles that of the Gemini.

The Orion is a four to six astronaut spacecraft based on the previously successful Apollo series in shape and design, and is intended to be ready for a 2015 mission. The main component of the Orion is the Crew Module, with a secondary Service Module. The 12-ton Orion Crew Module series is designed to be reusable for up to ten flights, with both International Space Station rendezvous and lunar sortie variants. The Orion Crew Module features a conical craft shape, as opposed to the winged vehicle body of the space shuttle, and is designed to splashdown when returning to earth as the previous Apollo vehicles did, and has an aeroshell heat-shield similar to that of the Viking series craft. The Orion is physically larger than the previous Apollo series that it is based on, with an emphasis in the lunar mission variant for longer missions than previously flown. One of the main features to facilitate extended lunar mission is the Orion's ability to remain in lunar orbit autonomously while the entire four-man crew descends to the lunar surface aboard the Altair Lander.

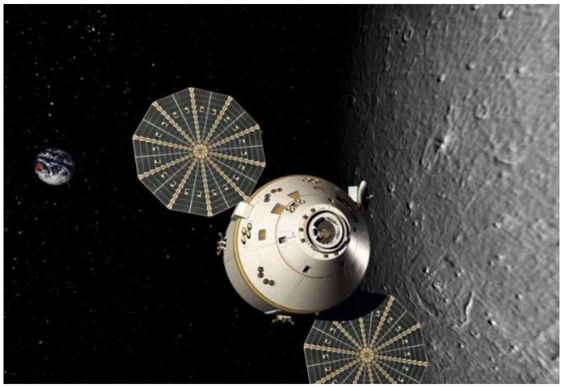


Figure 1: Orion space capsule in lunar orbit (Concept September 2006), taken from http://www.nasa.gov/images/content/156336main_Orion_lunar_orbit.jpg

The Orion Service Module is designed as the cargo and consumable goods storage aspect of the Orion system, as well as containing the primary means of propulsion and the retractable solar cells that will power the Orion's electronic systems, as opposed to the much heavier and more complex fuel-cells of the Apollo series. The Orion stack is designed for one-week missions, with the ability to carry out 210 day missions in conjunction with a Lunar Outpost. The solar panels provide the Orion stack with a long-term renewable energy source, stored in on-board batteries, allowing for longer missions. In addition, the Lithium hydroxide air scrubbers will remove and recycle Carbon dioxide from the air, and both waste water and urine will be filtered and reused by the same system as used on the ISS, as opposed to being expelled from the vessel as in the Apollo missions.

The Altair Lander is the key component in the plan to renew humanity's presence on the moon. While currently less far along in development than the Orion system, the Altair is planned similarly to the Apollo Lunar Module system, with descent and ascent stages designed to ferry astronauts to and from the lunar surface in conjunction with the Orion Command and Service Modules. The Altair is intended to take the Orion crew to the lunar surface while the Orion modules remain in autonomous orbit. Altair will be able to function as either a short-term lunar surface lander, an extended-stay lunar outpost, or as

Figure 2: Artist's rendition of the Altair lander. Courtesy of Wikipedia: http://upload.wikimedia.org/wikipedia/commons/0/05/New_Altair_design.PNG

an unmanned cargo transport, capable of carrying up to 23 tons, to bring supplies to a lunar settlement. For the early one-week missions planned, the Altair will include an airlock for astronaut safety, and will double as a useable feature for the establishment of the Lunar Outpost.

The space exploration vehicles currently under development by NASA are all designed with an emphasis on long-term lunar missions, the establishment of a lunar outpost, and the eventual ability to use that lunar outpost as a jumping-off point for missions to Mars. One of the primary missions of the Orion stack will be to facilitate the week-long missions planned for the assembly of lunar outpost components, with the craft then able to support astronauts on significantly longer stays at the outpost, including in preparation of Mars missions.

The Constellation Program also features NASA's first new launch vehicle in over 30 years: the Ares I Crew Launch Vehicle and Ares V Cargo Launch Vehicle. As their names suggest, the Ares I will be used for launching the Orion capsule, while the Ares V will be responsible for launching the Altair Lander, inserting the Orion and Altair vehicles into translunar orbit, and general-purpose heavy lifting, potentially for manned missions to Mars as well.

The Ares I is an incremental design over the Shuttle's launch systems, as well as the Saturn V. It is a two-stage vehicle, containing a solid fuel first stage and liquid second stage. The first stage rocket is a derivative of the Shuttle's Solid Rocket Booster. While the Shuttle's SRB has four segments internally, the new rocket will contain five, allowing it to produce more thrust and burn longer. This rocket is equipped with a parachute recovery system, allowing for post-launch performance analysis and reuse. The solid fuel in use is polybutadiene acrylonitrile, or PBAN, which is used in the Shuttle's SRB, the Titan III rocket, and hobbyist rocketry. This stage was successfully tested on October 28th, 2009 with the launch of the Ares I-X.

Figure 3: Ares I-X launch on October 28th, 2009.

Image credit: NASA/Jim Grossmann

The second stage of the Ares I will be a liquid rocket, fueled by Liquid Oxygen and Liquid Hydrogen. This rocket is derived from the Shuttle's External Tank and uses the J-2X engine, which is a variant of the J-2 engine, which was used extensively in the Saturn V. This new revision of the engine develops substantially more thrust than the J-2, as well as a higher specific impulse, but is also substantially heavier, in part due to its modification to be air-and vacuum-startable. The original plan was to more or less attach a J-2X engine to a fuel tank strongly derived from the Shuttle's ET, but this plan was dropped in favor of a more or less brand new tank, which features a lighter and simpler design that is similar to the S-II and S4B stages of the Saturn V.

The Ares V rocket iterates on the design of the Ares I, as well as borrows more designs from the Saturn V. The first stage consists of two solid rocket boosters, similar to those of the Ares I, as well as a new liquid rocket derived from the Saturn V, which is powered by six RS-68B rocket engines, which are upgraded versions of the engines on the Delta IV. The second stage of the Ares V is essentially the same as that of the Ares I; it is a liquid Oxygen/liquid Hydrogen rocket powered by a single J-2X engine.

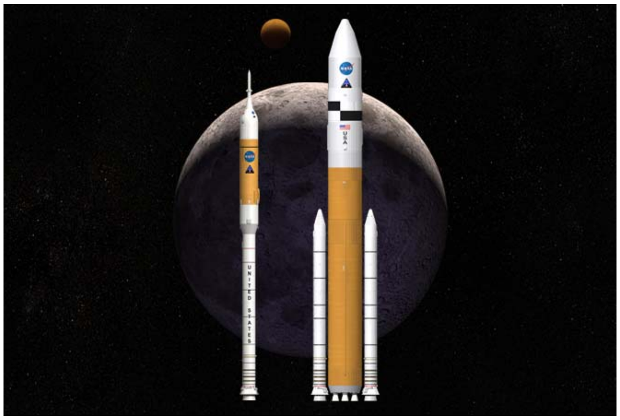


Figure 4: Ares I on left, Ares V on right.

Image credit: NASA/MSFC

As a result of the extensive overlap of parts between the Ares I and Ares V rockets, research and development costs have been kept low, and rocket construction will be done in the same facilities for both rockets, which will also save on costs. In spite of this, the White House is considering completely cutting the Ares I, instead relying on the Ares V for all lifting purposes, as a cost-cutting measure. Such a decision, however, would be rather foolish; the Ares I rocket is already substantially far into its development, and cancelling it now would completely waste several years and hundreds of millions of dollars of research and development. Additionally, the Ares V is essentially an Ares I secondary stage, two Ares I primary stages, and an additional rocket booster; it makes no sense to cancel the Ares I in favor of only using the Ares V when the Ares V is mostly an Ares I. Cutting the Ares I would save money now by halting its research and development, but could ultimately wind up being more expensive when Ares V rockets have to be launched when the smaller and cheaper Ares I would have been sufficient. Such a lack of commitment to space exploration is extremely disheartening, especially when it comes from the country that put man on the Moon.

Clearly, the most rational approach would be to require parts interchangeability between the mostly-developed Ares I and the largely-undeveloped Ares V, which even in the existing plans is a relatively easy task to accomplish. Rather than viewing Ares I development as a separate entity from the Ares V development, the White House needs to recognize that the Ares V development is a logical continuation of the Ares I; cancelling the Ares I but continuing the Ares V would only serve to decrease the flexibility of future missions, with a minimal at best impact on costs.

2.3 Where to Put It

One of the first important tasks for a manned lunar colony or outpost is selecting a location. There are three regions worth considering: the poles, the equator, and the dark side, and each has its advantages and disadvantages. Some portions of the poles are in direct sunlight over 90% of the time, with deep, permanently dark craters nearby that may potentially house water. Some of these regions, such as Malapert crater, have direct line-of-sight with the Earth at all times, which is extremely useful in maintaining a constant communications link. These polar regions, however, are substantially less explored than the equatorial regions, such as the original Apollo landing sites. The equatorial regions also have higher concentrations of Helium-3, due to the angle of incidence relative to the solar winds that are responsible for its deposition. The dark side of the moon, which has had no ground exploration yet, would also be an extremely interesting location for a lunar outpost. It is an ideal location for a very large radio telescope, as it would be completely shielded from Earth's radio waves, and has the highest potential Helium-3 concentrations, because the solar wind there is never deflected by the Earth's magnetic field. Unfortunately, very little is known about the dark side of the moon.

Ultimately, the best location for a first lunar outpost or colony is Malapert Mountain, on the rim of Malapert crater. There is very likely to be water in the nearby permanently-dark craters, such as Shackleton crater. It is almost always in direct or partial sunlight; it is only dark 7% of the time. It is always in direct line-of-sight with the Earth, which greatly simplifies communications, and at over 16,000 feet high, it is also in line of sight with a vast region of the moon's south pole. Even if there is no water ice at the South Pole, Hydrogen can be found in higher concentrations, simplifying the synthesization of water. The various deep, permanently-shadowed craters in the vicinity, such as Shackleton crater, are also excellent locations for telescopes. Infrared telescopes work best in ultra-cold environments, and these dark craters are a near-constant -150 C. These craters are also naturally isolated from Earth's radio interference and would be very good locations for radio telescopes. All of these telescopes could be easily powered, constructed, and maintained from an outpost or colony located on Malapert Mountain. Unfortunately, the predicted temperature range of this region varies widely; the only certainty is that the temperature is fairly consistent. Some sources speculate that average temperatures are around 35 degrees Fahrenheit, while others expect them to be much lower–as cold as -100 degrees Celsius. Both conditions, however, are manageable; consistent temperatures, almost regardless of what they are, can be regulated to a livable temperature.

Figure 5: Malapert Mountain, visible in the bottom-left. image courtesy Cornell University/Smithsonian Institution and Bruce Campbell.

Additionally, based on recent findings, NASA's Moon Mineralogy Mapper instrument onboard India's Chandrayaan-1 satellite has confirmed the presence of water not only in polar regions, but indeed across the entire surface of the moon. This water, unlike the hypothesized comet-deposited water nodes at the poles, is similar to the levels of water one would find in desert dirt–while it isn't wet by any stretch of the imagination, it is wet nonetheless. These water concentrations are likely to be denser at the poles, as the water evaporates over time, any water that doesn't escape the moon's surface would tend to gather in colder regions, slowly causing the water to migrate towards the ultra-cold craters of the poles. Based on this evidence, we can state with certainty that there is not only water on the moon, but usable concentrations of it in the poles. More conclusive and accurate data, particularly about polar concentrations, will be forthcoming soon, as NASA's Lunar Reconnaissance Orbiter and LROSS impactor are three months into their mission to provide high-resolution maps and search for water on the moon, particularly in the polar regions.

Now that a location has been established, a survivable habitat must be built and powered. Mount Malapert's extremely high solar exposure makes solar power an easy and effective choice. During the brief and rare periods of darkness, the base's backup power supply systems could be used; such systems could be thermonuclear, fuel cells, or solar panels located elsewhere on the moon. The fuel cells aboard the space shuttle have been used to provide power for up to 17 days without failure, and newer fuel cell systems are lighter, more efficient, and more durable. Thermonuclear power on the moon is extremely appealing, as radioactive waste isn't particularly problematic in an environment otherwise devoid of life and bathed in radiation. Such backup power supplies would be required, because damage to the primary source, such as micrometeoroids, would otherwise result in life support systems failure, placing the inhabitants in extreme danger.

2.4 Projected Population Levels

In order to determine feasible quantities of human presence on the moon, we will begin by taking a look at humanity's most recent space-inhabiting venture, the International Space Station, and then extrapolate from there to an ideal goal of an independent moon colony. Since the first ISS expedition, which entered the station in November of 2000, the ISS has been continuously manned. Up until expedition 20, in May of 2009, it was occupied by 3 people at any given time, but has been continuously occupied by 6 since May. The first module of the ISS, Zarya, was put into orbit in 1998, marking the beginning of the ISS's construction, but it was uninhabited until 2000.

Lunar construction will be substantially more demanding than low Earth orbit construction; for example, it is not feasible to construct the entire base on Earth in segments; rather, as much of the base will have to be constructed on site as possible. Additionally, the base will be primarily subterranean, which will necessitate extensive excavation. Water and oxygen harvesting systems will also have to be deployed before permanent occupancy is feasible, as well as facilities to recover other important chemicals, such as nitrogen. Based on these more difficult goals, we estimate that it will take 5 to 10 years of robotic construction, mining, smelting, and excavation before a permanent human presence can be established. During this 5 to 10 year period, 4-person manned missions, lasting around one week, will be made regularly aboard the Altair lunar lander, in order to evaluate progress and deploy new Earth-made modules or robots as needed. Such Earth-made modules would likely include power generation facilities, such as solar panel arrays, backup fuel cell systems, and hydroponic farm systems. Once a habitable lunar environment has been established, 4-person missions would continue, but for extended durations; probably on the order of 3 to 6 months, during which time the habitability of the moon would be evaluated, including things like long-term plant development, which has been found to perform reasonably well in low-gravity and low-pressure environments, or other biological research, such as fetus development, which is thought to require gravity to successfully happen, but thorough research into the strength of gravity required has not been done. Additionally, construction would continue during this time.

These four-man missions would completely disregard issues like gender and racial background; only the best, brightest, and fittest would be suitable for such missions, much like modern space shuttle and ISS missions; however, once a sufficiently large moon base has been established, and long-term or permanent residence becomes an option, such issues will need to be considered. Since one of the longest-term goals of a lunar base is to serve as an extinction-proofing system for humanity, we must consider what would be needed to repopulate the Earth. After 25 years, it would be reasonable to expect the lunar base to have reached a point where it could sustain a population numbering in the thousands, if not higher, and it can also be assumed that we have developed the ability to get people to the moon in groups larger than four at a time. At this point, people may be able to permanently move to the moon, which will require a revision in colonist requirements. First, a roughly equal gender distribution is desirable from the start of permanent colonization, as eventually more colonies will develop on the moon, and whole cities could begin to develop; starting with a gender balance will help to ensure that colonization and expansion continues at a predictable rate.

These first colonists will also have to be extremely skilled in their field; highly competent medical professionals will be needed to attend to virtually any medical emergency that could occur on the moon, as the nearest emergency room will be thousands of miles away. Skilled engineers and scientists will be needed to keep lunar facilities running smoothly, as well as to develop new technologies of lunar interest, such as specialized hydroponics systems or lunar expedition systems. In terms of racial background, the only thing to consider is multilingualism: English will be the official language of the colonies, since they stem from NASA missions, but several other languages will be highly desirable, including German, French, Russian, Chinese, Japanese, Hindi, and Arabic, as these languages are all spoken in the other primary space-faring countries. In regards to racial background, no consideration can be afforded; the moon will inevitably wind up as a melting pot society, which will likely eventually develop into its own racial identity, especially considering the harsh environment.

Within a hundred to 150 years, multiple cities should be constructed on the moon, and the moon's population will have exceeded 1 million people. At this time, it will likely be desirable for the moon to declare itself an independent country, due to the rapidly growing permanent population, commercial and industrial capabilities, and the substantially different requirements of government on the moon than anywhere on Earth.

2.5 Safety and Disaster Planning

One of the largest dangers to a colony on the moon is the effects of cosmic and solar radiation. During the Apollo missions, radiation shielding was minimal at best; the missions primarily relied on briefness of exposure and luck to keep the astronauts safe. The radiation-based dangers a moon-bound mission faces are three-fold: first, the launch vehicle must safely cross the Van Allen Radiation Belts, then it must safely pass through the space between the outer Van Allen Radiation Belt and the moon (cislunar space), and lastly it must keep the astronauts protected on the moon. During the Apollo missions, Van Allen Belt radiation was handled simply by crossing the belts as quickly as possible in their narrowest regions, minimizing the radiation dose the astronauts received, and the radiation went virtually unshielded. Indeed, the various Apollo modules and suits used no explicit radiation shielding, although the thick hull of the command module did effectively shield against solar and cosmic radiation sources. In the cislunar region, the solar wind is the primary radiation source, and it consists exclusively of high-energy protons and electrons; alpha and beta particles. Shielding against alpha and beta particles is typically very easy; a sheet of paper can adequately shield against alpha radiation, and a few millimeters of aluminum can shield against beta particles. However, the alpha and beta particles of the Van Allen Belts are extremely energetic; alpha particles in the outer belt are typically on the range of 100 KeV (thousand electron volts) to 10 MeV (million electron volts), while beta particles in the inner belt are typically on the range of hundreds of KeV to hundreds of MeV. When these super-high energy particles are slowed by traditional shielding materials, such as lead, secondary radiation is released, known as bremsstrahlung, which can itself be extremely dangerous. However, by more gradually slowing these particles with lower-density materials, such as plastics or water, the energy is released more slowly, resulting in lower, less penetrating secondary radiation. The radiation of the solar wind, however, consists of substantially lower-energy particles, typically on the order of 1 KeV, which isn't energetic enough to induce bremsstrahlung.

However, since all of these radioactive dangers are alpha and beta particles, which are charged particles, they can all be deflected magnetically, much like how the Earth deflects the solar wind. Since the particles are charged, they are subject to the Lorentz force, the process by which magnetic fields induce current flow. Essentially, when a charged particle approaches a magnetic field, it will be deflected perpendicular to the axis of the field in a direction dependant on the particle's polarity. In the case of the Earth, the magnetosphere effectively diverts nearly all of the solar wind away from the Earth in this manner; a very small amount of solar wind material may sneak by, but it is rapidly engulfed in the Van Allen Radiation Belts, which are also driven by complex interactions with the magnetosphere. Ultimately, these surges of magnetosphere-passing solar radiation are driven by the Van Allen Belts to either the north or south poles, where their collisions with particles in the upper atmosphere create the aurora borealis and aurora australis.

By simply generating an electromagnetic field around a spaceship or lunar expedition, it may be possible to safely deflect most, if not all, of incoming charged radiation. Currently, scientists at MIT are experimenting with superconductor-powered magnetic field systems for usage in future lunar missions, where magnetic fields supported by current in superconductors will take advantage of the Lorentz force to deflect solar radiation.

In terms of lunar construction, by far the simplest shielding can be readily provided by the lunar regolith, which may either be used to encapsulate surface structures, or structures can simply be built underground, as the lunar regolith samples returned by the Apollo missions have been proven to be rather effective at blocking radiation; just 18 centimeters of lunar regolith can safely block 200 MeV beta particles.

Disaster planning is a key part of all future space missions, whether to the moon, the ISS, or elsewhere. Current plans for Orion mission emergency procedures are extremely thorough, including emergency response options for during launch, en route to destination, low Earth orbit problems, problems in lunar orbit, problems on the moon, and problems on the way back. In-launch disasters, such as those of Apollo 1 and the Challenger shuttle, can be avoided with the launch escape system, which is a secondary booster on top of the crew module, which can fire and detach the module from the base rockets, giving the module the ability to make an emergency landing either on land or sea, at one of numerous emergency landing sites, including several in Spain and Morocco for lunar-bound mission trajectories, and the seas surrounding Great Britain and Ireland for ISS-bound missions.

The Orion modules also have the now-standardized docking systems, shared with the ISS, making in-space emergency response fairly simple; if, for example, heat shielding on the module is found to be damaged (like that of Columbia's), the module can simply dock with the ISS, which can be used as a temporary safe haven. Once the module has been determined unfit for re-entry, a backup crewless Orion module can be launched as a recovery vehicle, which the crew of the original Orion module can then take back to Earth. In the event of an event severe enough to disable the Orion's docking systems, an unmanned module can be scrambled to their location and the crew can perform an extravehicular activity in a microgravity environment to leave the damaged module and enter the rescue module.

Disasters that occur en route to the moon have a few options: they can use a lunar orbit to return them to the Earth, like Apollo 13 did, or they can use the moon as a safe haven with the Altair module; by proceeding to land on the moon onboard the Altair Lander, they give NASA ten days to scramble an unmanned Orion module into a suitable lunar orbit, which is plenty of time. If an Altair module itself is unable to return to the Orion vehicle, then the astronauts can seek refuge in the lunar outpost, where they will relieve the existing crew, who will then be return home when an unmanned Altair vehicle, such as those used for heavy lifting, can arrive and take them; the other crew will later use the original return vehicle, leaving the damaged Altair behind. On the other hand, instead of scrambling an Orion module, NASA could perhaps situate a sleeping Orion module in a lunar orbit that could be remotely activated and used for rescue missions, substantially reducing the time needed to complete a rescue. The feasibility of this, however, depends partially on the spacecraft's ruggedness in a deep-space environment; micrometeoroid damage could potentially render such a rescue craft unusable. Parking a craft in a low-earth orbit, then, may be a desirable compromise; it's a relatively safe region of space, and it can perform a rescue operation faster than a ground-launched Orion.

Planning for an actual disaster in the colony itself, however, is rather difficult. First, there is a wide range of threatening scenarios: loss of power, such as through micrometeoroid damage to the solar power systems; illness among the crew; solar flares, especially during a surface mission; crew injury; damage to life support systems, whether from micrometeoroids, solar flares, or other events, and numerous other such disasters. The first step to protecting the outpost is system redundancy; backup power supplies will already need to exist for the brief lunar nights, so they can also serve as redundancy in the event of solar panel failure. Decentralized life support systems are also inherently protected; if one set of climate control and atmosphere regulation equipment fails, there are already several others to fall back upon. Crew injury or illness, however, is a very difficult challenge, and will almost certainly require immediate mission termination, and extensive first aid training for the whole crew will also be required, as they will have to be able to stabilize a crewmate in the event of severe injury, which is substantially more possible on the surface of the moon than in the closed, controlled environment of the ISS.

Once a more long-term population presence is established on the moon, even if it is a small population (on the order of a thousand people), a highly trained medical staff is absolutely essential, and the need for it increases quickly as population increases; it may be feasible to bring back the crew of four to Earth if one of them gets dangerously ill, but regularly evacuating individuals or portions of an established colony to Earth for medical treatment will be prohibitively expensive. With any luck, widespread disease outbreak in the colony will be virtually nonexistent, due to the colony's extreme detachment from Earth; with even a mild amount of pre-launch hygiene, medicine, or sterilization (for cargo missions), things like seasonal flu outbreaks, E Coli, and other such modern plagues won't have to be a threat at all.

Ultimately, some level of risk has to be accepted. Going to space is quite clearly very dangerous, as history has shown us. Pushing the boundaries of what is possible for humanity is not safe; there will be accidents, and people may die. We can only hope to minimize these risks, and minimize the severity of their outcome; it would be foolish to expect to master space without danger.

Geomagnetic storms are a severe hazard to operations in space. Local near-Earth occurrences of severe space weather can be damaging to terrestrial electronics and operations, as well as a danger to satellites and manned installations in space. The combinations of magnetic interference, radiation, and ambient plasma events can cause a host of problems for humanity, both on and off the Earth.

The National Weather Service (NWS), through the National Oceanic and Atmospheric Administration (NOAA) provides meteorological predictions for space-borne activity in the same ways they provide for weather predictions here on Earth. Analysis of space radiation and electromagnetic interference levels, as well as solar activity, can provide an estimate of the Space Environment for the next 24 hours accurately, but it is much more difficult to anticipate anything but the largest and most severe occurrences, after that window.

Space weather prediction data is supplied primarily by two satellite sources. The Solar and Heliospheric Observatory (SOHO) was launched in 1995 as a joint effort between the European Space Agency and NASA, and the Solar TErrestrial RElations Observatory (STEREO) consists of two identical satellites designed expressly for observation of the sun. Together, SOHO and STEREO provide scientists with a massive amount of data, mostly observations of solar activity. Aspects monitored include activity in the outer layers of the sun (the makeup and activity of the corona, transition region, and chromospheres), analysis of the solar winds, observations on the interior structure of the sun, 3D analysis of Coronal Mass Ejections, radio frequency disturbances, and electromagnetic interference. By combining these analyses, accurate short-term predictions of space activity as it affects the Earth is possible.

Space weather predictions are critical for all manner of operations. The benefits of being able to predict the weather in space range from being able to plan missions in to space, to expectations on the functionality of telecommunications and electric power distribution on Earth. It is crucial to know conditions in space when planning a mission, so that times of severe activity and interference can be avoided. Cosmic radiation poses a grave threat to astronauts in space, but many other complications can arise from loss of communications or electronics functionality due to other types of interference including geomagnetic storms can jeopardize a mission as well.

2.6 Biological Concerns of Long-term Space Missions

From an Earth-based standpoint, the human body is a remarkable adaptable machine, capable of functioning in a variety of adverse conditions and environments. Many of the systems in the human body, however, are designed to work under the influence of gravity, and when gravity is removed from the environment, a number of problems and concerns appear.

The human body is designed from a structural standpoint to work against the effects of gravity. Osteon cells build bone in response to mechanical stress, and muscle development is based on usage and stress as well. In a zero or microgravity environment, there is effectively no mechanical stress acting on the body, so muscle and bone loss occur. Studies of astronauts aboard previous missions, especially long-term missions to the Mir and International Space Station indicate that bone loss can progress by as much as a 1.5% decrease in bone mass per month. Decreased muscle and bone loss leads to a significantly weakened and atrophied body and highly increased susceptibility to injury during physical activity or labor. In addition, the calcium freed from bones by decreased bone mass can manifest itself as severe and painful kidney stones.

There are also a variety of fluid changes in the human body in a microgravity environment. Human balance and blood flow are based on fluid systems designed to work under the pull of gravity. When gravity is removed, there are large fluid shifts within the body as blood flow and pressure adjusts, as well as a loss of orientation and balance. Fluids redistribute to into the upper body and head under microgravity, places those fluids are kept from pooling in normally by gravity. One of the most noticeable symptoms of this fluid redistribution is severe nasal and sinus congestion for the duration of the mission, as well as a nearly 20% drop in blood pressure. As the fluid setup in the body changes, the human immune system appears to suffer as well.

These structural changes caused by the removal of gravity have significant implications for the goal of keeping space-farers healthy and fit for duty. The eventual goal of the renewed lunar efforts is to develop a permanent establishment on the lunar surface, at which people would eventually live large portions or nearly all of their lives. People living on the moon are going to have a difficult time functioning and performing their duties after a few months or years if they are constantly suffering from broken bones and weakness due to low blood pressure. These symptoms are especially of concern for the proposed eventual use of the moon as a stepping stone for manned Mars missions. Astronauts aboard the long flight to Mars will not be able to perform their duties upon arriving on Mars if they have suffered severe bone and muscle loss.

Strict exercise and physical fitness regimens in current astronauts have worked to prevent or manage these low-gravity symptoms, but are only a delaying factor. Astronauts that return to Earth after long ISS stays still need to undergo months of physical therapy in order to regain bone and muscle mass, as well as immediate physical reconditioning on order to maintain such integral functions as breathing. If astronauts are to stay for years at a time or fly to Mars, some form of artificial gravity conditions may need to be developed for these astronauts to live in. Spending the bulk of their time in an artificial gravity environment would leave Mars astronauts in much better physical condition upon arrival to Mars, and capable of fulfilling their missions. Some form of improved physical maintenance conditions will have to be developed before the first long term inhabitants of the lunar colony can begin their stay. Pharmaceutical solutions are under investigation, but some previously unforeseen solution may be the key, such as body maintenance nano-machine implants or some biomechanical enhancement.

Microgravity environments also appear to have some significant and poorly understood implications for reproduction. Animal embryonic development studies that have been conducted indicate some severe deficiencies in space. Research done in embryonic development and reproduction has not yet yielded any conclusive results as to the cause of these problems, and will need to be researched further an addressed if humans are going to permanently live on the moon.

Isolation and increased stress felt during long term space missions can lead to severe psychological problems for astronauts. Isolation from Earth in a confined space with only a few other humans to interact with can lead to increased stress, irritability, insomnia, paranoia, and even psychosis. As the size of the human population on the moon increases, these problems could subside, and improved data flow technologies should help to alleviate the isolation from Earth that lunar colonists will feel. Astronauts are trained now to deal with these concerns, and are generally able to cope with these stressful conditions, and astronaut crews are rotated at intervals that prevent these long-term symptoms. The first few years of lunar settlers will be similar to ISS missions, with a rotating crew and relatively short term missions working towards a larger goal. Eventually, the best of the best will begin serving much longer term missions, and for the most part, simply have to deal with these conditions.

3. Lunar Colony Applications and Practical Uses

3.1 Lunar Energy Resources

One of the largest potential benefits of having an established presence on the moon's surface is the presence of the light isotope Helium-3 (He-3), containing two protons and one neutron. Helium-3 is useful in nuclear fusion research because in combination with the Hydrogen isotope Deuterium it can be used in a fusion reaction that releases no additional neutrons. Helium-3 is extremely rare on Earth, but can be found in higher concentrations mixed into the lunar regolith, as it is deposited by solar winds. Mature (having been exposed to the solar winds for the longest) lunar regolith appears to contain around 0.01ppm of Helium-3.

Establishing a lunar mining operation for Helium-3 would be extremely costly, and have to be on a vast scale due to the low concentration of the isotope, but would easily pay for itself if successful. Even though the concentration is low, early estimates based on research of the lunar surface suggest there is enough Helium-3 present to power the Earth through nuclear fusion for a number of centuries (approximately 1 million tons of Helium-3).

There are two schools of thought on how to extract the Helium-3 from the lunar regolith, but both rely on the same end principle of using extreme heat to bake the isotope out of ilmenite (magnetic titanium oxide $FeTiO_3$) regolith, the source from which Oxygen for fuel can also be extracted by a very similar process. There is some debate on the efficiency of first harvesting lunar regolith and mechanically crushing it down into a fine powder in order to separate just the ilmenite and heating just the ilmenite, or to simply harvest regolith and bake it all without mechanical separation. By extracting the ilmenite first and breaking it down, the processing of Helium-3 requires much less heat energy, but the mechanical process to extract the ilmenite is very difficult and inefficient itself, due in part to the low concentration of ilmenite in the regolith (between 0 and 20% depending on lunar region). Baking of unprocessed regolith requires on the order of 100 times more heat energy, but can extract 100% of the Helium-3 from that regolith.

Complex mechanical systems exposed to the lunar surface conditions run a very high risk of breaking down and requiring repair. In contrast, heat energy is one thing is massive abundance on the lunar surface due to the direct uninhibited sun exposure. A massive robotic extraction facility could harvest regolith from the ground underneath it and use massive solar panels, parabolic in shape to focus the energy into a kiln that heats the regolith to at least 600°C in order to extract the solar-wind deposited gasses, on average 0.01% of which will be Helium-3, extracted from the gases using low-temperature processing. In order to have a continuous source of un-harvested regolith, the ideal extraction facility would be mobile and have an approximately 4:1 energy return for harvesting. At the same time this process can be used to extract Oxygen for rocket fuel, hydrogen, nitrogen, carbon, and normal helium.

Solar power is above and beyond all other power sources the most infinite source of energy available to humans today. Solar energy can be tapped using silicon photovoltaic cells, which rely on absorbed photons to 'knock' electrons on the cell into a higher state of energy, thereby producing direct current electricity. Approximately 250 watts/m^2 reach the Earth's surface, after a massive amount of energy is lost traveling through Earth's approximately 11 km deep atmosphere. Solar energy collectors can harness solar energy in space at much higher rates, due to the lack of atmospheric refraction and interference, leaving an available amount of energy closer to the solar constant of 1,366 watts/m^2. The advantage to having solar collectors outside of the atmosphere is clear, and through microwave power transmission, the energy collected could still be received by people on the planet's surface using a surface based rectifier antenna (rectenna).

Solar Power Satellites (SPS) have been around in concept since the late 1960's, but through NASA evaluations were deemed too difficult and expensive to put into practice. In order to be effective, a photovoltaic Solar Power Satellite needs to have a large transmission antenna (potentially up to one square kilometer), and at the time of their evaluation, the energy and weight efficiency of photovoltaic systems was very poor.

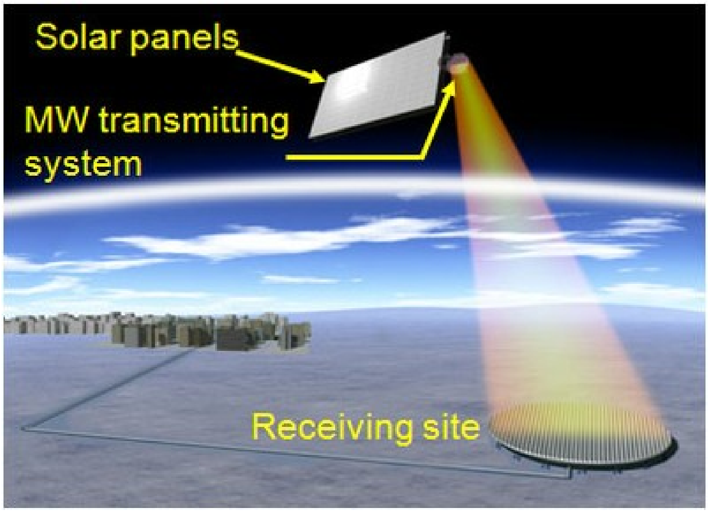


Figure 6: Diagram of the Solar Power Satellite System in action. Image courtesy Kyoto University Faculty of Engineering.

With the development of a lunar settlement, Solar Power Satellites have a potential at new life. The costs of launching and assembling SPS systems from Earth were deemed to be a crippling factor to the idea, but when based on the moon, the idea becomes much more practical. The moon contains almost all of the required materials in extractable forms to construct such apparatuses, and it is far easier and cheaper to launch things from the surface of the moon than that of the Earth. At the same time, a solar collectors derived entirely from lunar resources could provide limitless power to a lunar outpost as well as provide Earth-orbit systems that beam energy back to Earth for using the same microwave beam system. In addition, photovoltaic technology has rapidly increased in efficiency, both in regards to energy and size, to the point where effective cells that are considered cost-efficient have power conversion efficiencies of around 20%, and can be constructed wafer-thin, lightweight, and flexible. Due to the still poor actual efficiency of the photovoltaic cells, an effective SPS system will require many (50-100) square kilometers of collection surface, providing between 5 and 10 gigawatts of power per satellite.

The lunar surface is ideal for surface-based Solar Power programs as well. Lunar regolith is rich in minerals including Aluminum, Titanium, Iron, Oxygen, and Silicon. Silicon is required for the construction of the photovoltaic cells, the metallic minerals can be used in the construction of the SPS systems, and Oxygen is used as rocket fuel for liftoff. Plans for a lunar outpost already include the processing of regolith for Helium-3 extraction and Oxygen extraction, with the leftover minerals being usable as raw construction materials for the actual outpost, so the manufacturing infrastructure will already be in place to construct the Solar Power Satellites. Due to the absence of a lunar atmosphere, effective solar energy collection can also be done by surface-based collectors at a rate much higher than that of solar energy collectors on the Earth's surface.

Lunar Solar Power Satellites will need to be in geostationary orbit (35,786 km), in order to maintain reception of the microwave beam for energy transfer, and have an advantage over ground-based collection systems in the amount of time they can remain in the path of solar energy. Any solar power collection system is going to rely on a network of collection units and power receivers in order to maintain a constant source of power. The problem lies in determining an orbit that provides the maximum sun exposure while maintaining contact with the reception system.

The location of the rectennas on Earth is a source of debate, due to the necessities of matching up with lunar satellites or relay satellites in between, the size of the rectennas (potentially a mile in diameter), and perceived safety concerns. Rectennas rely on receiving antennas linked to electric rectifiers, which convert alternating current (AC) to direct current (DC). Rectifiers are capable or converting the received microwave radio beam into direct current for power consumption or storage. A four-diode bridge rectifier is capable of performing Full-wave rectification, providing the maximum efficiency conversion of the microwave beam into electrical current.

Studies done by NASA during the evaluation of SPS programs determined that Microwave Power Transmission only requires a low (23 mW/cm^2 at the center, to just 0.1 mW/cm^2 at the outermost edge) intensity radio beam, with leakage comparable to that from Microwave Oven (5 $mW/cm^{2)}$, with a receiving efficiency of approximately 85%. The U.S. government safety regulation allows unlimited occupational exposure to microwaves in the 2.45 GHz range of 10 mW/cm^2. The microwave beams are operating at low intensities and frequencies to avoid Rain Fade (the absorption by atmospheric rain of microwave radio frequency signals at frequencies at or above 11 GHz), the beams should not be at all harmful to biological material. Because of the low intensity and frequency signal, spread out over very large surface area rectennas, the actual signal intensity at any one point will be extremely low, and studies indicate that the only potential consequence of modern microwave power transmission beams could be a slight increase in temperature directly in the beam's path, but nothing so strong as to cause actual damage. The microwave radio frequency radiation being used is non-ionizing, and cannot cause any actual 'radiation' damage to organic matter. Animal testing concluded with no health issues, so the system appears to be safe. A Solar Power Satellite system should be able to provide near continuous power (around 99% continuous), and would be able to supply an effectively limitless amount of power to both the Earth and moon, made possible by the establishment of a lunar outpost.

3.2 Lunar Mining

John S. Lewis's *Mining the Sky* is a broad-reaching look at the relationship between the Earth and space exploration. *Mining the Sky* contains an overview of the development of space exploration so far, as well as some varied potential benefits of a renewed focus on space exploration.

One of the main points of the early chapters is to place blame on the short-sightedness of early space programs for the current state of space-ignorance. Space exploration techniques and technology were developed during the Space Race at an unprecedented rate by the United States and United Soviet Socialist Republic. The problem today is that, with no discernable goal other than to beat the opponent to whatever arbitrary goal had been established, the Space Race did not get us very far. The moon landing was a patriotic triumph of American ingenuity and industry, but little social or technological advancements followed our reaching the lunar surface. With no real use for the moon planned, the triumphant American space program dwindled after reaching that arbitrary goal.

What little research has been conducted from the data gathered during the Space Race and other later efforts has shown us that there might be great potential benefits to establishing a proper space presence. The unfortunate hindrance to any further space efforts is the financial nature of hard science research in today's world. I agree with Lewis's conclusion that the current research system is flawed, in that base science research is nearly impossible to get funding for without also working on some tangible technology to garner interest from both private and government investors. The military-industrial complex of 21st century America makes it exceedingly difficult to acquire funding for a project that would have as long of an overhead before producing a product as a long-term space mission.

Lewis spends the rest of *Mining the Sky* exploring various economically beneficial reasons to further out space exploration, as well as a 'big-picture' analysis of the practicalities behind such endeavors. One of the most important considerations of modern society today is the search for affordable energy sources. Analysis of what data we have has shown that both the moon and a number of nearby asteroids are rich in resources, the acquisition of which would be substantially beneficial to both the world-wide society and economy. Lewis's space projects look good on paper, but the problem we have today is that these projects are still dependent on financially costly research that is not being funded. The projects in *Mining the Sky* all have potentially lucrative returns, but the analysis of those returns is still based on rough non-fiction writer's research and not hard scientific determination. The whole plan gets hung up by needing proper and extensive research to determine the true feasibility of these endeavors before any actual projects can be developed. One of Lewis's greatest criticisms of industry in *Mining the Sky* is the short-sightedness of modern industry. All of the projects outlined in *Mining the Sky* have the potential to be unfathomably lucrative and beneficial to society, but are still dependent on an unprecedented level of foresight, ambition, and spending from historically conservative investors.

Many discussions of space exploration stem on motivations of 'benefiting all of humanity' and the like, but all fall short of the truth that benefiting humanity is not typically the most sound investment, and all of these potential space projects are dependent on truly massive amounts of funding that is not there. Some greater motivation is required to jumpstart our space based efforts. The lunar landing did not need a great and tangible promise to investors, because it was driven by the goal of beating the Soviets to the moon. The Space Race could have accomplished so much more if there had been greater and more defined goals of the work, and if both the USA and USSR had not lost all momentum after the decisive moon landing, then the current state of human space dominance could be vastly different. The current environment, however, has lead to a much greater understanding of the resources available on the moon, and the potential benefits of being able to access those resources. I believe we are headed much more in the right direction today than we were a decade ago when John. S. Lewis wrote this book, and that the potential has been realized for a further and expanded effort towards space exploration and establishment.

3.3 Planetary Defense

Another practical application of a lunar base is the detection of and protection against Near-Earth Objects. Near-Earth Objects, or NEOs, are objects whose orbits bring them into close range of the Earth, where close is defined as having a perihelion distance of less than 1.3 AU (Astronomical Unit; the average distance between the Earth and the Sun). Near-Earth Objects are typically broken down into three categories: Near-Earth Meteoroids, which are objects with a diameter less than 50 meters, Near-Earth Comets, which are the majority of comets visible from Earth, but typically have no impact threat, and Near-Earth Asteroids, which pose by far the biggest threat to life as we know it, which are broken into three subcategories, depending on their orbit. Atens asteroids are those whose average orbital radius is less than one AU and maximum orbit radius (aphelion) is greater than Earth's minimum (perihelion); that is, asteroids that spend the majority of their time orbiting between the Sun and the Earth, but can cross paths with the Earth. Apollos are asteroids whose average orbital radius is greater than Earth's, but whose perihelion is less than Earth's aphelion. Lastly, Amors are those whose average orbital radius places them in orbit between the Earth and Mars, and whose paths never cross the Earth's. Atens and Apollos can pose direct threats to the Earth, but, by definition, Amors cannot, although their orbits could evolve into Earth-threatening orbits in the future. In 1998, NASA set out to discover at least 90% of all NEOs larger than 1 kilometer in diameter by 2008, under the Spaceguard Goal. As of June 10th, 2008, 742 NEOs larger than 1 KM had been discovered, account for 79% of the estimated 940 NEOs. Of these 742 NEOs, 3 are larger than 10 KM, and are suspected to be the only 3 of such size. Currently, the plan is to continue the surveying of space for previously-undiscovered NEOs, with one of the more substantial efforts being the construction of the Large Synoptic Survey Telescope (LSST), for which the NEO survey is just one of many projects, due to the diminishing value in the continued survey. The Spaceguard Survey has been widely regarded as a success; we are substantially more aware of potential threats, and we have substantially more advanced warning in the event of a large impact possibility. The Canadian Space Agency is launching a microsatellite in early 2010 to orbit the Earth for the purposes of discovering and tracking Atens NEOs, whose near-sun orbits are particularly challenging to monitor from planetary facilities.

However, knowing the orbits of existing NEOs is only half the battle; what can we do about potential impactors? This issue was recently addressed at the 1st IAA Planetary Defense Conference in the context of the NEO Apophis, which currently has a one in 45,000 chance of impacting the Earth in 2036. In 2013 and 2022, Apophis will make two passes near the Earth; during these passes, more precise measurements will determine the probable path for the 2029 flyby, whose path will determine whether or not an impact will occur in 2036 or shortly thereafter. In a worst-case scenario, where the 2013 and 2022 flybys point to a guaranteed impact in 2036, there are some options at our disposal, which were the core subject of the PDC. The two primary options are Gravity Tractoring the asteroid out of the 610 meter band that will result in a 2036 collision, and also away from nearby keyholes (positions that, when the asteroid passes through them in 2036, will result in a collision further down the line). Such a mission would begin in the spring of 2021, to arrive at the asteroid in early 2022. Such a mission would then survey the asteroid to get a high-precision measurement of its trajectory. In the event that the trajectory is still unfavorable, the spacecraft can then, over the course of roughly ten years, slowly nudge the asteroid away from danger zones.

Gravity Tractoring works as a result of Newton's Law of Universal Gravitation; since every object attracts every other object with a force proportional to their masses and inversely proportional to the square of their distances, a moderately large spacecraft can impart a force on an asteroid from an orbit around the object. By imparting a force on the object, a spacecraft can change its momentum, resulting in a change in velocity, which will result in a change in the object's orbit, potentially protecting the Earth from disaster. For example, say there is a 100 meter, 1 billion kilogram object whose orbit threatens Earth, but a change in velocity of 1 centimeter per second would put it in a safe orbit, and our tractor has five years to do so. The change in momentum required to make the adjustment is M*V, which for our object is 10 million meter-kilograms per second, or 10 million Newton-seconds. Since we have five years over which to adjust the course of the object, we can divide this quantity by 5 years (in seconds) to get the average force we need to impart upon the object, which gives us just .0634 Newtons, on average. If our tractor's mass is 40,000 kilograms, then it will need to maintain a position just 105 meters above the object's surface for five years to change the object's velocity by 1 cm/s.

The Kinetic Energy approach would most probably be used in conjunction with a monitoring spacecraft, potentially one with Gravity Tractoring capabilities, and consists of using a high-energy impact with the asteroid to abruptly change its course. It is significantly faster than the GT approach, but it is substantially less accurate; it would knock the asteroid out of the primary impact path effectively, but could easily put it in one of the many keyhole positions that are close to the primary impact trajectory.

These scenarios are not possibilities; they will come to pass. It may not be Apophis, with its 1-in-45,000 chance, but there are numerous other objects of substantial size and probability, such as 2007 VK184, a 130-meter wide asteroid with an impact probability of 1 in 3,000 in 2048. While these particular events will likely never come to pass, significant impacts happen, and humanity needs a plan; luckily, we have some very good ideas to work with, but they pose particular difficulties. Gravity Tractoring is an extremely lengthy process and, if the mission had to be aborted partway through, the asteroid in question could still potentially impact the Earth. Who will decide and how is it decided how the path will be adjusted over the course of the tractoring? The geopolitical ramifications could stagnate such a project or escalate tensions between already-unfriendly nations.

However, NEOs are more than just a danger, they are an opportunity. Many NEOs originate in the asteroid belt between Mars and Jupiter, from which they are expelled by orbital and gravitational resonances with Jupiter. NEOs present the unique opportunity of short-ranged, potentially manned missions to objects that would otherwise go completely unexplored. Not only are they unique in their origins, they are readily accessible; sometimes more so than the moon, due to their velocity relative to the Earth and their substantially smaller gravitational forces. Manned missions to NEOs are a logical stepping stone between people on the moon and people on Mars; they could be used to help understand some of the challenges of putting people on Mars, but in a less-distant, more controlled environment. Travelling to NEOs would also allow us to more accurately determine their composition; ultimately, we could end up mining NEOs for resources, especially for use in space exploration.

3.4 Telescopes and the Night Sky

Another use for the Moon is as an observation point, because it has several beneficial characteristics for a wide variety of telescopes. Much like in deep space, optical telescopes would perform extremely well on the lunar surface, due to the lack of an atmosphere; additionally, the vast majority of the materials for making massive telescope mirrors and lenses is already on the moon, as the lunar dust can be mixed with a special epoxy and spun into massive mirrors, on the order of 50 meters, five times larger than the largest on Earth. Additionally, unlike space telescopes like Hubble, these telescopes are built on-site and don't have to worry about maintaining an orbit, allowing for optical telescopes of an unprecedented quality and magnitude. Such telescopes would be capable of analyzing Earth-like planets in other solar systems for potentially life-supporting features, such as atmospheric methane or ozone, or the presence of oceans and continents. High-power optical telescopes on the moon could also be used to monitor, track, and detect NEOs for the purposes of planetary defense.

Additionally, massive radio telescope arrays on the dark side of the Moon would be able to take an unprecedented look deeper into the history of the universe. On Earth, radio telescopes have to deal with massive amounts of noise and interference, ranging from humanity's use of radio waves for communication to interference caused by the ionosphere. On the dark side of the moon, a radio telescope observatory would be completely shielded from Earth's radio waves by the Moon, and the lack of an atmosphere would remove the possibility for atmospheric interference. Such a radio telescope would be extremely useful for a variety of purposes. It would, for the first time, be able to study the 'Dark Ages' of the universe's history–the first billion years after the Big Bang, starting shortly after microwave background radiation filled space, covering the time during which stars and galaxies first came into existence. Such telescopes could also be used to study the behavior of the Sun, galaxy collisions, and space weather in general, potentially leading to more predictable space weather and electromagnetic interference, which could increase safety of space travel.

In addition to visible light spectrum telescopes, the polar craters on the Moon offer phenomenal potential for infrared telescopes. Since infrared cameras and telescopes are essentially imaging heat, they must be kept at cryogenic temperatures for maximum performance. On Earth and in orbiting observatories, cryogenic cooling systems must be used; however, many of the Lunar South Pole craters, such as Shackleton crater, receive no sunlight ever and, as a result, are phenomenally cold; temperatures inside the crater never exceed 100 Kelvin, which is comfortably within the operating range of modern infrared detectors. While these cryogenic temperatures are beneficial to all types of optical imaging systems (and thus optical telescopes), the benefit is by far the most substantial for infrared systems.

By taking advantage of the Moon's lack of atmosphere, natural radio-shielding, and cryogenic temperatures, we can build observatories many magnitudes more capable than the most cutting-edge observatories of the present. These observatories will be easier to construct and maintain, will be cheaper, and will be substantially more capable than their terrestrial or space-based alternatives.

3.5 Deep-Space Travel

Another key advantage of a lunar base is such a base is a substantially easier launch point than the Earth, due to having a much weaker gravitational field. The escape velocity of an object is dependent on the radius of the body being launched from, and the acceleration due to gravity of the body. Using Newton's law of universal gravitation, we can derive an expression for the kinetic energy needed to escape an object from the gravitational field of another object. For the purposes of these derivations, an object is fully escaped from the gravitational field of another object when it is infinitely far away. While impractical, the energy needed converges to a finite amount, providing a meaningful result.

The weight of an object of mass *m* at a height *s* above the center of an object is g*m*(r/s)^2, where g is acceleration due to gravity of the primary object and r is the radius to its surface. By integrating s from the surface, *r*, to infinity we can determine the total kinetic energy needed to escape:

$$\int_{r}^{\infty} g \cdot m \cdot \left(\frac{r}{s}\right)^{2} ds$$

By substituting in 9.8 m/s^2 for g, and 6738 kilometers for r, we can calculate the escape energy for a mass *m* for Earth.

$$\int_{6738}^{\infty} 9.8 \cdot m \cdot \left(\frac{6738}{s}\right)^{2} ds$$

Which solves to 66,032.4*m kilojoules. Generally, the function solves to g*m*r. In order to turn the kinetic energy required into the escape velocity, we need to use the equation for the kinetic energy of an object of mass m moving at a given velocity v, and set it equal to the kinetic energy of escape velocity.

$$\frac{1}{2}mv^2 = gmr$$

Conveniently, mass cancels out completely, leaving us with:

$$v = \pm\sqrt{2 \cdot g \cdot r}$$

Clearly, negative escape velocities can be disregarded. On Earth, this equation gives us an escape velocity of 11.492 kilometers per second. On the Moon, g is only 1.62 m/s^2 and the radius is only 1,737 kilometers, giving an escape velocity of just 2.372 kilometers per second. In terms of kinetic energy, we can compare the required energy for a lunar launch to that of a terrestrial launch by establishing a ratio dependant on escape velocity, again using the equation for kinetic energy of a moving object:

$$\frac{\left(\frac{1}{2}m\cdot 2372^2\right)}{\left(\frac{1}{2}m\cdot 11492^2\right)}$$

The ratio conveniently turns into a ratio of the square of the escape velocities, assuming the mass of the object being lifted is constant. This ratio is $\frac{351649}{8254129}$, which is between 1/20th and 1/25th the amount of energy for an object of the same mass on the Moon as on the earth. That means it takes about 22 times more energy to lift a given object from the Earth than it does from the Moon. Since the mass of lifting rockets is substantially higher than that of a payload for a heavy lift (in the case of Earth to a lunar orbit, the Saturn V was capable of lifting 1% of the rocket's mass as payload), we can treat payload mass as negligible in this ratio, and then interpret this ratio as roughly a scalar for the payload size a rocket of a given mass and power can lift to a significantly distant orbit. This means that a standard heavy lifter rocket, like the Saturn V, can lift (conservatively, since such a massive payload is not negligible) twenty times more from the surface of the Moon than from the surface of the Earth. In the case of the Ares V, that's a payload of over a million kilograms off the surface of the Moon, which is astronomically large.

In conclusion, launching objects from the surface of the Moon for deep-space exploration, such as a manned mission to Mars, large-scale satellite construction, or truly any effective usage of space would, in the long run, be substantially more cost-effective, energy-efficient, and would have a significantly higher payload limit from the surface of the Moon than from the Earth.

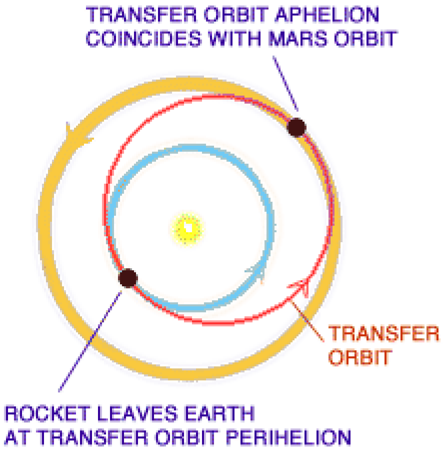
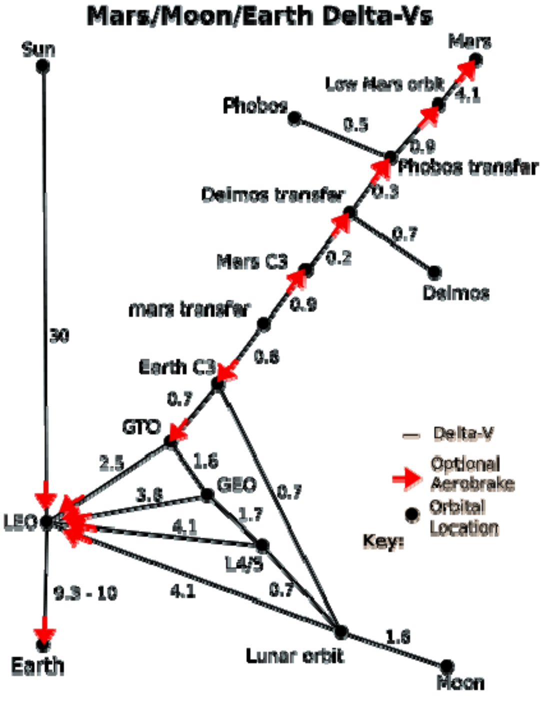


Figure 1. Hohmann Transfer Orbit. Source: JPL

When we speak of various orbits and transferring between them, we speak in terms of delta-V, which is the change in speed of the object to transfer it from its initial position to its final position, and we can calculate the delta-V required for a variety of different orbital transfers, including the Hohmann orbital transfer, which is frequently the lowest-energy transfer orbit between two points, and is commonly used for moving satellites from low-Earth orbit to Geosynchronous orbit, moving things to translunar orbits, or for sending satellites to Mars; for positions beyond Mars, Hohmann transfers are impractically slow, and gravity assists are often used.

In general, a Hohmann transfer consists of two bursts of delta-V, with a large coast section in between. The first burst occurs at the starting orbit, changing the circular orbit into an elliptical orbit with a semi-major axis from the center of the original orbit to the edge of the target orbit. The second burst occurs when the object is at the target orbit, which results in a circular orbit at the target radius. In terms of transferring objects from an Earth orbit to a Mars orbit, it's a good bit more complex than that, as the object has to transfer from a geocentric orbit to a heliocentric orbit to an aerocentric orbit (an orbit around Mars), all of which have their own delta-V requirements, as well as the delta-V requirements of an Earth-to-geocentric, Moon-to-geocentric, aerocentric-to-Mars, or any other such maneuver. However, the delta-V for each segment of a trip is independent of the rest, so once each given leg of an orbit is found, it is merely a matter of adding up the required delta-Vs to find the total delta-V of the trip.


Mars/Moon/Earth Delta-Vs

n.b. Not all possible routes are shown
delta-v's are in km/s and are approximate

Figure 2. Mars/Moon/Earth Delta-Vs. Source: Wikipedia.

Based on approximate delta-Vs as presented in the Wikipedia article on the subject (see bibliography) in figure 2, we can compare approximate Earth-to-Mars delta-Vs to Moon-to-Mars delta-Vs, to get a rough idea of the advantage of Moon-based Mars missions. By simply summing along the lines connecting a given orbit or position to another, we can find the minimum delta-V route. For a mission launching from Earth to landing on Mars, this consists of a launch to LEO, a transfer to GTO, a transfer to Earth C3 (escape velocity), a transfer to Mars, a transfer to Mars C3 (escape velocity), a transfer to Deimos, a transfer to Phobos, a transfer to Low Mars Orbit, and lastly a landing on Mars, with a total Delta-V of 19.5 to 20.2 km/s. A Moon-to-Mars mission would consist of a launch to lunar orbit, a transfer to Earth C3 (escape velocity), and from there it would match the Earth-to-Mars mission, for a total Delta-V of just 9.3 km/s, less than half that of a Earth-to-Mars mission; in fact, it's the same as the low-end delta-V requirement for a Earth-to-LEO transfer. Since propellant usage is an exponential function of delta-V, it's quite clear that missions to Mars that launch from the Moon would be substantially more affordable than Earth-to-Mars missions.

To verify the data presented in Figure 2, we will examine one of the paths: the delta-V required to transfer from low-earth-orbit to geosynchronous orbit. The total change in velocity for a Hohmann transfer orbit is given by: $\sqrt{\frac{\mu}{r_1}}\cdot\left(\sqrt{\frac{2\cdot r_2}{r_1+r_2}}-1\right)+\sqrt{\frac{\mu}{r_2}}\cdot\left(1-\sqrt{\frac{2\cdot r_1}{r_1+r_2}}\right)$

Where μ is the standard gravitational parameter of the primary body (the Earth, in this case), r_1 is the starting radius, and r_2 is the ending radius. For the case of Low-Earth-orbit to geosynchronous orbit, we get:

$$\sqrt{\frac{398600.4418}{8378}}\cdot\left(\sqrt{\frac{2\cdot 42164}{8378+42164}}-1\right)+\sqrt{\frac{398600.4418}{42164}}\cdot\left(1-\sqrt{\frac{2\cdot 8378}{8378+42164}}\right)$$

Which is a bit over 3.3 km/s. While this doesn't exactly match the 3.8 km/s provided by figure 2, this can be attributed to using a different value for a low-earth-orbit, as the accepted radius for a low earth orbit is between 160 and 2,000 kilometers (our calculations use a 2,000 kilometer LEO).

4. Societal Implications – A Look to the Future

4.1 Society on Earth

In our model analysis of the next 100 years, the energy concerns of humanity will be solved for the foreseeable future thanks to a large human presence on the moon built around the harvesting of Helium-3 from the lunar surface as the fuel of nuclear fusion. When the concern of finding affordable sources of energy is removed from the human planning, personal freedom to live where and how one pleases is allowed to flourish.

The population of Earth continues to increase. Even if ten-thousand people are living on the moon by the end of the century, there will still be drastically more people living on the Earth than there are now. Many urban and developed areas in heavily populated countries such as the United States, India, and China, are facing population density and congestion problems. There are plenty of places on Earth that we could use as new population centers, but these locations are currently unutilized because of their remoteness and harsh environments. With effectively unlimited energy, developed urban centers could be drastically expanded and new population centers could be developed.

Developed urban centers will continue to grow as centers of economy and population. With energy no longer at a premium, urban centers can grow both out and up to fit more people. Population centers such as New York City have always expanded upwards in order to gain more space, and this process will undoubtedly continue. If most of New York City or Dubai development became modern high-rise skyscrapers, a great deal more space would be opened up for use within the existing footprints of these cities.

New population centers can also be created in previously un-developed areas of the globe, including the Northern reaches of Canada in North America, as well as the Siberian Tundra in Asia. With plentiful nuclear fusion energy, regions such as these can be developed into acceptable population centers, taking the pressure off of extremely densely populated places like China and India.

All of the future development will not be in the name of fitting more people into existing dense population centers. With the development of plentiful energy as well as technological advances in areas including robotics, the rich will be able to move further away from the bustle of urban life. Mostly robotic out of the way estates are a potential development from the wealthy, allowing them to lead mostly isolated lives without sacrificing any amenities. Plentiful energy will allow resource distribution to reach further, allowing these isolated estates to move to more and more remote locales, away from the increasingly crowded life in developing areas.

4.2 A Day in the Life

If lunar-harvested Helium-3 fueled nuclear fusion solves the world's energy crisis and technology, the sprawling urban centers of today we be able to thrive and grow at a previously unheard of rate. Internet connection speeds has already made it possible for a variety of jobs to be performed by employees from the comfort of their own home. With cheaper energy, it becomes economical to bring resources, including essentials like groceries, even closer to the consumer than ever before. As urban buildings get larger and taller, the technical worker or the future could very easily never have to leave the confines of his multi-purpose residence complex.

The average day in the life of a technical employee might be contained within a single building. He will awake in the morning in his apartment and eat breakfast consisting of groceries purchased from the food mart in the bottom of his building. Because energy costs have fallen so much, the grocer can afford to maintain a chain of smaller food retailers in each of the many sprawling living center buildings cropping up in urban commerce centers. When he is ready, the employee will sit down in front of his computer, and clock in to the corporate high-speed network of his employer. Internet speeds and bandwidth have been increasing rapidly since its public inception, and with cheap energy it will become affordable and desirable for internet service providers to upgrade the World Wide Web infrastructure to the highest technological standards and maintain cutting-edge performance. Our employee could work in any number of industries, from IT support to corporate office work in the cubicle of the future–his apartment. As human space proliferation continues, he could even be a researcher working on remote space-borne experiments, controlling robots onboard an automated low-earth orbit research station. If he is a space researcher, perhaps he goes up on a commercial low-earth orbit flight quarterly to check up on his projects hands-on and resupply the facility's experiments. Lunch will be taken during his break hour from groceries just like his breakfast. In the afternoon he might have a real-time corporate meeting with members around the world to discuss workloads and project planning. When he has finished his work for the day, he will log out of his work terminal, and the company's automated finance division will deposit payment for his day's work directly into his universal bank account. For recreation at the end of the day, our employee will likely stay in front of his computer for any number of reasons, or perhaps attend a building-hosted social event with his neighbors. While not a communal living environment, these modern all-in-one buildings will likely develop a self-contained social structure similar to a college dormitory floor, as these neighbors shop, dine, and potentially work together all from the comfort of their own homes. After a hard day's work, our employee of the future might not feel like cooking himself dinner and decide to go down to the ground floor and dine at one of his building's restaurants.

The employee of the future might take time off to visit his family on occasion if they are not nearby, or keep in touch with friends from school this way. If he has earned a Christmas bonus from his employer, he could certainly afford to travel, as travel costs will have decreased dramatically. A high-end vacation might now include a stop on the moon to see the sites, by way of commercial low-earth orbit flight to a spaceport in orbit around the earth. From there a proper space transport will ferry people to and from the moon for the equivalent of an extravagant terrestrial vacation today. He might even simply head out to his well-off parents' primarily automated country home out in terraformed northern Canada for the weekend. For the most part, however, everything he needs is in his skyscraping residential building.

4.3 Society in Space

Deep space colonization will come to pass. In the relatively near future, it will be possible for reasonably large groups of people to completely remove themselves from the modern human society, much as the first colonists of North America did. Such colonization ships would be most practical if constructed in space, such as in a lunar orbit, which would allow for substantially larger vehicles than could be launched from the Earth. Then, the limiting factor on colonizable locations is ship self-sufficiency; man-made objects have already travelled well past the most distant planets of our solar system, and have taken merely years to get there. These regions are, without a doubt, the most hostile place imaginable for humans to travel to, much like North America was 500 years ago. Using conventional rocket systems and gravity assisted trajectories, it is possible to get people to these new frontiers. The only significant issue to overcome is scale; ideally, such a ship would be capable of housing and sustaining at minimum several thousands of people for at least a year.

Let's look at the potentially difficult limiting factors involved. First, we need an adequate energy source for everything from life support systems to flight control systems. Nuclear fusion systems will be the ideal solution, as solar energy in the deeper regions of space is insignificantly small. First, nuclear fusion will have to be adequately developed, which will hopefully happen within the next two decades; then, it has to be at least somewhat miniaturized and made safe enough and reliable enough for space travel. Next, we have to have a source for oxygen and water, preferably a self-sustaining one; high-density hydroponic farms could possibly solve both the oxygen problem and the food problem, but once again, space may be too limited. Current space missions have already developed water recycling technology quite well; another few decades of advances will no doubt improve things there, but what we have now would likely be adequate. Lastly, the issue of radiation shielding will have to have been more or less solved for more basic lunar systems.

Propulsion is possibly the most interesting area. Existing propulsion systems would probably work, but there exist far greater possibilities, such as solar sails. Solar sails harness radiation pressure of light, typically sourced from a star (in our case, the Sun), but also potentially sourced from laser systems. While such systems are unlikely to exhibit particularly high levels of acceleration, their acceleration comes from essentially an endless source of particles moving at the speed of light, which in the vacuum of space, translates to phenomenally high potential speeds on the order of significant fractions of the speed of light. Such solar sail-driven vehicles will likely hold the key to proper interstellar travel, opening the door for exploration of what lies beyond the edge of the solar system, and potentially spread humanity to neighboring solar systems.

As a person, this ability to "leave it all behind" is profound. It will be possible to completely forgo all Earthly woes, problems, politics, and prejudices. Colonizing space will doubtlessly be a dangerous task, but the rewards are truly awesome; it will be the most important thing any person has done for mankind ever. If all else fails and humanity goes extinct, these colonies and the efforts of these people will be the longest-lasting artifacts of our society, civilization, and species.

If things go well, it's a chance to reinvent societal norms; it's a chance to redefine a culture. It's like the religious freedom the pilgrims were pursuing, but on a grander scale. For the individual who is throwing away his life on Earth to go live on Mars, in the Asteroid belt, or some moon of Jupiter or Saturn, it's a complete change of lifestyle. While Earth may be an even more densely populated highly interconnected bustling world full of strangers, government, and mistrust, it is a chance to change lifestyles to something more secluded and private, in an area devoid of government with at most a few thousand other people on the entire planet or moon. There will doubtlessly be a lot of work to do for a person in such an environment, but that has always been the case when settling the great frontier; this time, however, there will likely be a lot less farming and a lot more robots.

Day-to-day responsibilities in such a remote colony would still likely focus around food production and subsistence; robot maintenance would probably be one of the most important daily tasks. In addition to subsistive farming, the community would share some overheads such as power generation, which in a nuclear fusion world, would likely require highly-trained professionals and more robotics.

4.4 There is Another Way

75 years from now, space travel will be as normal as air travel is today. Tech companies will do research and development in both Low Earth Orbit and on the Moon. Some people are likely to live on and work in space for 2-3 months before returning to Earth or the Moon for their vacation. The way we go about our daily life will be completely different, as will our ways of interacting with technology. Gone will be the days of sitting in front of the computer, as will be using a keyboard for input and a stationary monitor for output. We are already seeing trends away from this; laptops have replaced desktop computers in most situations, and devices like smart-phones are becoming more powerful, cheaper, and more widely-used. Similar advances are being made in human-computer interaction. Voice recognition capabilities are becoming more and more prevalent in our daily lives, as are image recognition. The technology exists for systems which rely solely on webcams for full control of computers, such as the SixthSense system, which is currently the best glimpse into the computing world of tomorrow. By combining a mini projector and a webcam into a wearable garment, any surface becomes a monitor and everything can be controlled through speech and hand gestures in a more streamlined, natural way. This is the world of tomorrow. Such a gesture-driven, human system could be easily extended to interaction with, and control of robotics.

As fossil fuels become a thing of the past and as energy concerns vanish, we will be able to recover and reverse the environmental damage of the past century. As the population of Earth increases dramatically over the next century, so will our available places to live. By applying the technology we will have developed to live on the Moon, we will be able to increase the habitability and desirability of some of Earth's harsher environments, such as the deserts.

Between these paradigm shifts in how we work and where we can live, there is no need to resort to city-buildings; we will not be forced to live in beehive-like structures, although such options are likely to exist. As technology advances and plays a more integral role in our lifestyle, how we interact with it and how it impacts our daily life is changing, and will continue to do so. As technology becomes more important, it becomes less invasive, and humans are social animals; we will not isolate ourselves in city-structures and work only with robots in our apartment cubicle. Becoming a space-faring society doesn't have to hold any massive paradigm shifts in the way we live life like the printing press or the telegraph did; families will still be nuclear, but instead of having grandma and grandpa living in Florida, they may be living on the Moon.

Recommendations For Future IQPs

The most obvious next step for a future IQP is to revisit many of the same issues in five to ten years, and analyze how successful we have been in accomplishing the highlighted goals. Other IQPs in the nearer future could explore the ethical issues of many of the technological advances that could be brought on by future space exploration. Another area of interest for future IQPs could be a more in-depth technical analysis of space transportation options and technology, covering topics such as solar sails, traditional rockets, and nuclear propulsion.

Another area we only briefly covered is current and future legislation governing the usage of space, as well as the issue of militarization of space; a geopolitical look at the ramifications of increased accessibility of space would be able to provide unique insight into the development and advancement of humanity in space.

Conclusion: Space, the Final Destination

The establishment of a moon base might seem to be a fanciful notion to some, but there is a very real possibility that a moon base will be a crucial resource for the continued proliferation of humanity. The moon is the closest extra-terrestrial object to Earth, and appears to be far more useful than scientists believed after getting their first Apollo samples back for analysis. The moon is abundant in energy resources that may become essential for human survival in the not-so-distant future. Helium-3 is the most promising nuclear fuel we have discovered, required for the ideal nuclear fusion power production scientists are working towards. Extremely rare on Earth, the atmosphere-free nature of the surface of the moon makes it a far superior source of Helium-3 than anywhere on Earth. In a similar vein, the lack of atmosphere on the moon makes it an ideal location for solar power collection at a level unachievable on Earth.

By the middle of the 21st century, humanity will be a space-faring species. Moon colonies will have begun to expand into full-blown cities. It will be economically feasible for lunar townships to develop in otherwise-uninhabited regions, as advances in robotic technology will provide the mechanical means to make these otherwise-desolate regions inhabitable. By this time, a key change will have to have occurred: spaceflight will have to have been commoditized, most likely in a manner similar to current air travel. It will be a field dominated by a small number of large-scale spaceline companies, with capabilities paralleling current air travel–small to medium-sized commuter flights to various points of interest in Low Earth Orbit, such as research labs, space resorts, or deep-space hubs; moderate-range "transatlantic"-scale flights from these LEO spaceports to either lunar orbit hubs or directly to the surface; and, down the line, deeper-space missions to places like Mars.

A large permanent human presence on the moon, self sustaining with its own infrastructure and resources, opens up our use of the moon for a variety of purposes. The idea that a previously undetected object could strike the Earth and cause a cataclysm is a very real possibility. Even if the statistical likelihood is small, the risk of what would happen is so high that we must act to protect ourselves from such a disaster. A self-sustaining moon establishment would serve as a second home for humanity, keeping all of our proverbial eggs out of a single basket. In a less morbid sense, the moon also makes an ideal looking station for the detection of potentially dangerous Near-Earth Objects (NEOs), as telescopes can operate much more accurately and efficiently in the lack of atmosphere in the lunar environment. Early and accurate detection of potentially harmful objects could be the key to averting such a disaster.

The low gravity on the moon makes it suitable for another host of applications as the launch-pad for further space exploration. It requires much less energy to launch things off of the moon than Earth, making it an ideal staging ground for space exploration missions, including those to Mars, humanities' next closest exploration goal. Analysis of the lunar surface composition has found that the moon is ideal for such elaborate functions. Oxygen is present and can be harvested for use as rocket fuel, and the refinement process will leave lunar inhabitants with an abundance of metal resources useful for construction of both the lunar outpost and the vehicles that will carry explorers beyond the moon.

Additionally, the commercialization of space travel will enable those with the funds to do so to fly in private spacecraft, much as amateur aviation enthusiasts and ultra-wealthy celebrities do now. Unfortunately, due to the complexity, expense, and size associated with Earth launched vehicles which is unlikely to change in the foreseeable future, it is extremely unlikely that private commodity spaceships will ever be on the market, at least on Earth; such car-level vehicles may eventually be a possibility on smaller bodies, such as the Moon, and will almost certainly exist for inter-satellite personal transportation, either between satellites orbiting the Earth or Lunar-to-Terrestrial satellites. At times even further in the future, it may be possible to lightly colonize the asteroid belt with such vehicles operated out of Mars or the Martian Moons.

By commoditizing space travel, all of space will be opened up to the average Joe. For as little as a few thousand dollars, it will be possible to travel to the Moon in search of new opportunities, adventures, or just some unorthodox vacationing. By embracing the commercialization of space, we will enable scientific advancement with additional funding, as well as public and commercial interest.

As a whole, the space tourism industry will be an incredibly strong driving force. As it stands now, the tourism industry earns over 1 trillion dollars per year, and is growing steadily; this is over fifty times the size of NASA's budget, to put numbers in perspective. The tourism industry is large enough to financially support entire countries; by embracing the human interest in space, the economic behemoth could be harnessed as a driving force in space exploration and development. "Disneyland Moon" is practically inevitable; if its construction and development can aid the development of the Moon, we should embrace and encourage it.

On a personal level, this will, as a whole, represent an unprecedented level of personal freedom, which comes during a time when technological advancements seem to be gradually infringing on privacy; it will be possible for an average person to take an adventure to a world of complete freedom– either temporarily at a space resort, or to permanently go "off the grid", be it in a Lunar, Martian, or Martian moon outpost, or to the vast real estate of the asteroid belt. Much like the America of the 1500s and 1600s, these regions will be months of travel away and communication will be limited at best. We are on the verge of a new era in the history of mankind and exploration and progress, with space as the next fertile and infinite ground for humanity to conquer–space is truly the final frontier.

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