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Earthly Implications of a Return to the Moon; Fusion, Health, and the Space Industry

An Interactive Qualifying Project Report:

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Abstract

The following is a social impact study of a technology assessment in which logical extrapolation was used as a method to predict the social impact on Earth resulting from a return to the moon. This study focused on advances in three areas; power, biotechnology, and the space industry.

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Introduction

This Interactive Qualifying Project (IQP) examines the social implications of a moon race between various space agencies identified in the forecasting phase of a previous study. In that study, a space race between the United States and China was predicted with both countries reaching the moon approximately in the year 2020. Once on the moon, China will setup a lunar base on the South Pole where they will begin mining operations. The United States, according to the forecast, will be using their base as a training center for a planned Mars missions. The forecast study initially considered the idea that the United States would settle on the equator of the Moon; however the findings of this previous study suggest that the US will also settle on the South Pole. These increased activities in space should prove to have immense social implications on Earth.

The first step in this study was to examine the previous work describing activities on the Moon and analyze the implication of this work in terms of discrete space age innovations. A critique of the forecast was completed in order to establish a base line from which we extrapolated our own ideas to form an understanding of the predicted scenario.

To determine what areas will be most affected by the renewed space race, and the extent of the effect on these areas, this study will use historical analogies that apply to the moon race. From the situation predicted in the forecast, comparable situations from the past will be researched. From there, the likely

outcome of the current situation can be extrapolated. No technological breakthroughs will be assumed as a technological breakthrough is something that cannot easily be predicted due to an unexpected advance in current technology. The time span established for this study is approximately the next fifty years. By that point the ramifications of the United States' and China's relative space related efforts should be clear.

Through the use of historical analogy and our analysis of the activities that will occur on the moon, we make the case that three important issues with significant impact both on the moon and on Earth will need further analysis. These activities, which include power, biotechnology and the space industry, are discussed below.

The power industry currently relies heavily on fossil fuels as an energy source. By 2050, the world supply of oil will be dwindling and a large supply of alternative energy must be found. Once on the moon, the lunar bases will require tremendous amounts of energy to run the operations planned by China and the US. These bases will require large stores of power, with no fossil fuels available on the moon meaning the use of alternative energy sources is mandatory. The similar need of both the Earth and the moon for alternative sources of power will require the development of new alternative power technologies that generate large amounts of power. This study will look into the possible effect that development in space will have on power.

The human body is affected greatly by any environment that differs from that of the Earth. The most troublesome problems stem from the effects of gravity in space and on the moon that is less than that on Earth. These effects are similar to that experienced by people with osteoporosis and other aging ailments. The United Sates currently spends an enormous amount of money to combat and treat these conditions. NASA also spends great amounts trying to understand the affect of the environment on the moon on the body. Therefore there is a great likelihood that solving these problems in space could lead to solutions to medical problems on Earth. The implications of solutions for the conditions would be of great impact on Earth.

These new lunar activities predicted by both the forecast study and this study will require an infrastructure larger than is presently in place. The space industry will have to grow to support these missions. This will create a larger more active and more profitable and productive industry on Earth. The economic ramifications of this enhanced space industry will be enormous. This study will look into the effects of this expected growth in the space industry.

Through the use of logical extrapolation and some historical analogies, this study will enable us to predict what the effects of lunar colonization will be, the relative size of these effects on Earth, and then examine the effects that will have the greatest impact in greater detail. The goal of this study is to predict the

changes in certain domains and create awareness of these possibilities so that the implications of this new space race can be examined and prepared for effectively.

Background

Our project is taking over where the previous project ended. The previous group attempted to establish a timeline for the second space race between the United States and China. This group used results from the space race in the 1960's between the US and Russia as a guide to predict the unfolding of the predicted future space race. To do this, they first looked at the background of the two nations involved in the previous race and the new nation in the race, China. They then researched the events and affects that shaped the outcome of the first race, and compared that to potential affects that will shape the new race. They then established the most important events leading up to the new race, and predicted what effects these events will have on the new race. From there they were able to suggest a timeline or forecast for the next 30 years of the space race.

The first section of the previous group's forecast is a history of the Mercury, Gemini, and Apollo programs. This history covers the creation of the Saturn V rocket and followed by a discussion of the Gemini missions and a close look at lunar probes launched previously to the Apollo missions. The background section then covers the current status of NASA as it pertains to the second space race, discussing the need of a new launch vehicle, a new capsule.

The background section returns to the history of NASA from a more in-house analysis. They look at the accomplishments of NASA from 1992-2001. During this period NASA managed to cut costs while increasing productivity due to

management changes brought about by NASA administrator Daniel Goldin. Management problems in NASA during the 80's; specifically the mistakes in management leading to the Challenger disaster are discussed. NASA's fiscal history is then examined, followed by a budget outlook until 2020 estimating funding at about $22 billion. The forecast looks into the public support NASA has received over the years. A current survey said that 80% of polled adults said the shuttle program should continue. The forecast then sums up the current state of NASA saying:

"Today NASA is still biased toward manned space, but it is more centralized and sluggish than before. It is less capable of doing missions and unwilling to take new risks. NASA is no longer the high performance organization it used to be and needs to be "reinvented" since it has been overly focused on the shuttle as a means to build the space station for too long."

Next, the background section turns to the History of the Russian space program. First discussing the launch of sputnik's 1-3. The Vostok missions are then discussed, mentioning how the first manned vehicle in space was actually intended to crash land. The first time man and woman entered space was during the Vostok missions. The Soyuz missions took the place of the Vostok. The Soyuz spacecrafts were much more complicated then the Vostok crafts, and were intended to be lunar flyby space crafts. However, after the USA's landing on the moon, the Soyuz missions changed goals.

Russia established space stations after losing the space race to the US. Following some failures and minor successes, the highly successful space station MIR was put in orbit. According to the forecast MIR is the pinnacle of successes in the Russian space program.

The forecast also gives an extensive biography of Sergei Korolev; first discussing his childhood, then talking about his work on the first ICBM, then his leading role in Sputnik, Vostok and Soyuz. Furthermore stating at the time of his death, Korolev was working on a moon rocket.

Next, the background section covers the affects of communism on the space race; it mentions the attitudes toward space of each of the Russian leaders and discusses how Korolev was nearly killed in prison under Stalin.

The background of China as it pertains to the new race is then examined. The forecast mentions the history of the Chinese space program, specifically the Long March Rockets. From 1969 to 1999, the Chinese have had four launch rockets, LM 1-4. Each of these had increased capabilities from the previous version. The Shenzhou is China's first manned spacecraft, and was launched in 2003.

The pace of the Chinese development is also explained. The forecast states that: "However, the manned space program still has not sped up and will need to, to be able to meet some of their announced (and our forecasted) goals." The current technological status of China's program is next presented, according to the forecast; the Shenzhou is basically a next generation Soyuz.

A history of China since WWII is presented next. The purpose of this history is to explain China's reasoning for attempting to go to the moon. First mentioned is Mao's control of China and the "Great Leap Forward" and the "Cultural Revolution" China's current economic and political views pertaining to its space program is evaluated and concludes that as long as economic stability is maintained in China, they are very likely to go forward with their plans to go to the moon. The Chinese government sees it as a way to show their technical prowess and as a sign of their arrival as a world power.

The Methodology of their forecast is then explained, stating that: "Our method for making a forecast of what will occur in the Chinese and American space programs over the next 30 years will be comparative across time and place. We'll look at what happened in the previous space race between the United States and the Soviet Union and make a projection, taking into account things that will be different this time around."

They then go about this task starting with Russia during the previous space race. The history of Russia's space program from Sputnik to MIR is reviewed, and the significance of Korolev is restated. The budget of Russia's program is then examined; apparently the space program was so important to Russia that they were willing to foot the enormous costs even though they couldn't afford it. They fixed this by cutting spending on other more vital programs. The ideology of the Russian space program is then summed up as: "The Soviet space program was built on a

single goal; propaganda to show the superiority of the system that produced such technological prowess."

The United States role in the first race is also discussed. The purpose for the USA's creation of NASA was to catch up and surpass Soviet technology feeling that Russia's superior capability with ICBM's constituted a great threat to national security. Later, NASA was used as a means to show that the USA was as just as advanced as Russia. NASA eventually developed the ideology that: "Indeed, Space was expected to be the key to a new Renaissance period. NASA spokesmen also added that exploring the unknown is part of human nature."

The economic and ideological status of the nations involved in the new space race is explained; starting with China. The forecast sites China's "White Paper" where its goals are stated, and elaborates that China's people are very enthusiastic about going into space, and see it as a source of national pride. Also stated is that China's space agency CNSA/CASC currently has an annual budget of $2.3 billion versus NASA's current $15 billion.

NASA's current ideological status, according to the forecast, hasn't changed much across the years, and plans to come up with completely new technology for this second space race. However, the forecast discusses NASA potential lack of public support for lunar missions. On the other hand, the author's of the forecast feel that an establishment of ambitious goals could reignite public interest in space.

The forecast states some conclusions they made based on the background information collected. These conclusions are drawn from the key factors established in the methodology section of the forecast: current technological level, annual budget, current experience, and public support. Based on these factors the forecast estimates that the Chinese would land on the moon around 2020. Taking into account these same factors for NASA, the forecast establishes that the USA will probably land on the moon around 2020 as well.

Finally, the forecast is stated in a brief synopsis. They first establish that the USA will land slightly before the Chinese, probably around 2018, with China landing around 2020. The prediction then states that the Chinese have established a base in 2029 next to a crater near the pole of the moon where they have found water. Their base is setup as a mining community to mine precious metals encountered on the moon. Since the Chinese have established a mining community their base was constructed underground to protect the inhabitants from harmful radiation. The final Chinese base will hold about 20 people.

In 2030, the US is in the process of constructing a large base at the equator with the purpose of building a spacecraft for an upcoming mission to Mars. The base is very complex because of its complicated goal. Therefore this base will take longer to realize, around 2038 the US base will be complete with possible mission to Mars around 2040.

The forecast seems very fixated in the analysis of the previous space race. Because of this, there are both assets and faults. The positives of this method are that it presents a very realistic situation, as well as sound reasoning for the speculations they were forced to make. A fault seems that the changes in unrelated technology and the distribution of information are ignored. In the first space race computers were primitive and communication was slow. Now computers are able to do much more than 40 years ago, and communication across vast distances is almost instantaneous. Furthermore, this method does not take into account some major technological advances. This includes the German V-2 rocket which was an impetus to space travel in the first place. In addition, further research shows that it is likely that both the US and Chinese bases will be near the South Pole, where most of the water is located. Overall the forecast seems a good estimate of the general advancements of the space programs toward the setup of permanent lunar bases.

Last year a team of students looked at the new moon race between China and the United States. Subsequent to their findings it was realized that there were many ideas that were not looked or covered in depth. This year eight groups took what they did not finalize and continued where they left off. All of these projects based themselves on last years but each was very different. These groups examined the actual habitat on the Moon, Space Breakthroughs, etc. Even though the groups accomplished different goals, they managed to be interconnected in

many ways. Some of the information and ideas that are presented in this work are due to the efforts and findings of these various groups. This information was found to be related to the new moon race as well as the social implications of the moon race and therefore was used for the project. Group meetings also offered ideas that were found to be very advantageous and helpful to this study. Some of these ideas included what the lunar base may look like and the space platform ideas. From the platform idea it was clear that there would be a renewal of the space industry in order for the race to commence. A group that was focused on habitats provided the ideas on the features of the base, and from this, power options became an issue.

Helium 3 was researched as a possible power source and plays a critical role in the power issue of our project. Ideas on microgravity and what it would truly mean to a person and their health was contemplated. This lead to the finding that there are many affects on the human body and they must all be addressed. Without the cooperation of the groups, these single thoughts would never have come together to form a broad understanding of what these bases would encompass and thus, this project would not have been possible.

Prediction

The year is 2050 and there are two distinct Moon bases with two distinct purposes. The first one has been set up by the United States and is a practice base for a base on Mars. The second one has been set up by China and is a mining base for the precious element Helium-3 which is used for fusion. There are launch vehicles going into space at least once a month to supply the bases and also to travel to one of many platforms in space.

The practice base for Mars is an ever changing base because the United States wants to find the best technology to get the best idea of what to expect from a mission to Mars. The first step to building a base was to find some sort of sustainable habitat. Many different models were used with an inflatable being the first. The inflatable habitat proved vital to the early development of the Moon base because it was very simple to assemble. The base was sent up on an early mission and it was then operated remotely from Earth and was then inflated so it would be ready when the astronauts arrived later. This inflatable had all the essential equipment to keep the astronauts alive, however it was deemed not useful at the time. This was because the astronauts wanted to explore the vast lunar surface and the inflatable habitat was only appropriate for short distance exploration.

The next habitat that was tested was the concept of the Habot. Habots are habitats and robots all in the same machine. This mobile base would incorporate science experiments and living quarters all in the same machine. It was almost the

equivalent of a nomadic way of living. The Habots would travel in groups of six and link up after arrival at their destination. This was crucial because the astronauts could then travel between the Habots and it would create a semi permanent habitat that would have a communications link. The Habots were powered by solar power which was generated on a satellite and beamed by laser to the module. The robotic legs were essential for the tough terrain of the lunar surface and proved to be very useful. The Habots were the final design because of the fact that the base can be moved around to varying locations.

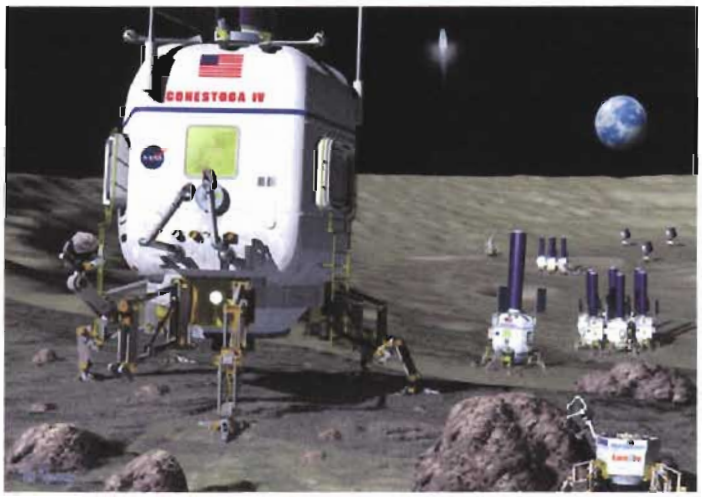

Figure 1: Artist's Rendition of what a Habot might look like

Even though the Habots were the final design, there were various larger facilities that were permanent and never moved. These bases were on a bigger scale because they were more easily sustainable. These habitats were not as useful as the United States had hoped due to their inability to move to different locations and other reasons. Even though the Habots were able to move, they did not move

fast enough for the astronauts to get a good grasp on the vast potential of the lunar surface and therefore many vehicle designs were tested out as well.

Since this base's purpose is a mock base for a mission to Mars, the key idea was to try the concept of self-sustenance or living off the land. This proved to be a very daunting task as there is no vegetation on the Moon. Many experiments were conducted in the way of growing vegetation on the Moon and have shown that it can in fact be done. Most of the vegetation is in the permanent base and the Habots use other methods for food.

These permanent bases will require a huge amount of power to operate. There are many key elements that must always have power in order for the base to thrive. There will be a communications room that will require a great amount of electricity as well as power for the infirmary and a recreation room.

The first form of power on the Moon will be nuclear fission. Even though there is radiation involved with fission, no other alternative power supply was available that would generate enough power to supply the base. Solar technology never really advanced enough to use it as a main power supply for the base. This would have been a favorable source due to the fact that the sun's rays are free; however, there was just not enough power generated. There are still hopes that a breakthrough can occur where there is no more need for nuclear power generators.

The only other viable power source that is not nuclear fission is nuclear fusion. However, at the start of the lunar base, fusion power was not an option

because the technology was not yet developed. Tests on fusion power were created on the Moon to see if the fusion could become a reliable power source. An active fusion generator has been created with enough power to supply the base. With the abundant supply of Helium-3, only a modest mining facility with a small processing center is needed for this base. This base is not part of the Helium-3 trade that China is involved with and thus does not need any substantial equipment.

The United States decided that the best location for a Moon base would be near the South Pole because of the supply of water. There are approximately fifty people living on this mock base for Mars. This number includes commanders to complete all necessary paperwork and make sure that everything is running smoothly on the base. Medical personnel are also essential as these astronauts are living in an environment that is unlike the Earth. As of yet, there have been no deaths to astronauts while on the base however, there have been a few broken bones and minor cuts and scrapes. The medical field has advanced greatly as a result of the new space program with new treatments for bone loss on the Moon due to the one-sixth gravity that is experienced on the Earth. There is also a vast crew of experimenters that are performing experiments on the Moon to learn everything that can be learned from the Moon. Most of the experiments are contained in the Habots that move around to different areas to study the different terrains on the lunar surface.

There are also approximately fifty astronauts in the platform program. Platforms are used instead of satellites. They are basically docking bays for all of the instruments that are normally found on satellites. These platforms are man tended meaning that occasionally, a space ship will go up and the astronauts will check on the instruments and replace them if necessary. There will not be a pressurized cabin for the astronauts to live in and therefore the voyages will be short.

This program was started about 2020 and its purpose was to become acquainted with continuous space flight. The platforms paved the way for the lunar bases in that they created a necessity for a build up of the space infrastructure in order to support the growing trend in platform technology. The commercial businesses are pleased with the platforms because they do not require as much money to operate their instrumentation in space. The consolidation of instruments on the platforms has created a widespread growth in the Global Positioning Systems technology the cellular phone technology as well as other new technologies making it cheaper than ever to own one of these products.

The next big base on the Moon is the mining facility. The highest concentration of Helium-3 was found to be near the equator of the Moon therefore, this is the location of the facility. Even though most of the water is concentrated at the South Pole of the Moon, the equator was chosen because of the abundance of Helium-3, which was a higher priority and cash crop for China.

There are approximately thirty people living on this Chinese base with most of them having had strip mining experience on Earth.

Overview

A technology assessment is a means of researching a certain technology with the goal of establishing an understanding of the potential impact on society that said technology could have. Many different types of technology assessments exist, and indeed there is no clear definition of how to complete a technology assessment. This is due to the fact that the effects of a technology and the ways of understanding them vary greatly depending on what kind of technology is to be studied. For this study, the technology assessment will include three areas: a forecast of related fields, impact identification, and an impact analysis.

The forecast of related fields obviously begins with a forecast of lunar colonization already completed by the forecast team. An understanding of the technological requirements of a lunar base must be developed. From here, this study will identify potential solutions to these problems on the moon. Next, an understanding of the pros and cons of these solutions were established and compared to other solutions so as to decide the most likely achievable solutions to the issues of lunar colonization.

Once the solutions were identified and understood, it is possible to attempt prediction of the implications of these new technologies. However, not all technologies have an impact on the Earth, if the problem experienced only exists on the moon, than the ramifications on Earth are small. Identifying the technologies that will have the greatest effect on Earth is imperative to this study.

After the implications have been identified, analysis of the implications can begin. This starts with a greater understanding of the area that will be affected, and its' state before the new technology is available. Then the significance of this area with consideration of the new technology is established. Finally, the impact of the new technology is shown by comparing the status of the involved field with and without the new technology.

From the forecast, the largest problems to be dealt with in lunar colonization are:

1. Supplying the base with water
2. Food and other supplies
3. Protecting the base from radiation
4. Providing the base with electricity
5. Protecting the inhabitants from the effects of lunar habitation.

Solutions must be found to these problems in order for lunar colonization to occur to a sustainable extent

To provide water to the lunar bases, the most likely solution is to gather water ice from the South Pole of the moon, to do this, a system of gathering the water ice must be established. This would be similar to some sort of mining operation on Earth. However, this situation will have little effect on the Earth because water is so plentiful here.

Protecting the base from radiation is also a must for sustainability. Also, having a base of adequate size is a must for any operations planned on the moon. The space agencies must come up with a method of assembling a large enough base and a way of shielding the base to protect it or at least those inside the base. This will require research into the type of radiation on the moon and also different methods of assembling a lunar base. This will be of little consequence to the Earth because the radiation on the moon is not felt here on Earth, and assembling a lunar base is nothing like construction on Earth.

A large source of electricity must be established on the moon, Due to the lack of fossil fuels on the moon this source of electricity must come from alternative energy sources. On the moon there are three possible power sources: solar, nuclear fission, and nuclear fusion. This is of great importance due to the fact that the Earth's supply of fossil fuels is running out; the moon could serve as a model of how to generate power without the use of fossil fuels.

The affects of the moon on the human body are numerous, however those that are most applicable to Earth are bone and muscle degradation. Both of these are due to the difference in gravity on the moon. These symptoms are similar to that of the aging process. Any solution to the medical problems caused by microgravity could lead to treatment of these ailments, which could lead to a longer happier life for many people on Earth.

To provide for the massive amounts of food and other supplies that the astronauts on the lunar base would need on a regular basis, a large infrastructure to transport supplies must be established. This infrastructure will require a larger effort by the space industry than is currently possible. This larger effort will require result in growth of the space industry. This growth will have a large effect here on Earth by providing more jobs and increasing a country's revenue.

The most important areas to look into for the implications on the Earth are the rise of an alternative energy as a viable power source, the treatment of certain conditions brought about by microgravity but also occur as part of the normal aging process, and an increased size and capability of the space industry. These results are the three major areas this study will discuss in greater detail.

In addition to limiting the study to the areas that will change greatly, other constraints must be set on the study. These include:

1. Assuming a gradual development of technology as opposed to assuming unexpected breakthroughs
2. A timeframe of the study must be established and the restriction to socio-economic impacts. These are setup to keep the technology assessment focused on the most likely effects of a new technology.

No technological breakthroughs were assumed for this study. This is due to the fact that breakthroughs are generally unexpected events. Also the impact of a

technological breakthrough is incredibly hard to predict as it affects so many aspects of human life.

The timeline established for this study is approximately from now until 2050. This year was chosen because it gives enough time for the full impact to occur, but is not so far that making predictions becomes impossible. The reason for focusing on fusion power, bio-technology, and the space industry is that studying the effects of lunar colonization on these areas involves strong technical knowledge which is a strong point of the group.

Results: Fusion Power

On the moon, one of the major problems to overcome is supplying power to the base and other equipment. The planned increased development of the lunar base requires a substantial power supply be established. The fuel cells and batteries used during the previous lunar missions will simply not supply enough power. Therefore, for lunar colonization to be a success, the space agencies must find a solution to provide adequate power for the lunar bases.

To complete this section of the study, research of literature about fusion power, other energy alternatives, the power industry on Earth and current fusion research is required. This was accomplished through the reading of books outlining different energy options. Scientists have long known that the supply of fossil fuels would eventually run out; therefore there is extensive literature about possible replacement energy sources. Also, a strong understanding of nuclear fusion was necessary, so researching the experiments of the University of Wisconsin's fusion department was done. Finally, information on the various other power types was required and gathered from the department of energy's website. With the knowledge gained from these sources an impact study was possible.

There are various ways to provide power on the moon, both conventional and alternative modes of power should be considered. The four main power possible power sources are: fossil fuels, solar, nuclear fission, and nuclear fusion. All of

these must be looked into in detail to decide the best process for providing power to the moon.

The first and most conventional method is fossil fuel power. These fuels include oil and coal, which are the most commonly used fuel sources on Earth. Fossil fuels could definitely provide enough power on the moon; however, getting enough to the moon is the problem. There are absolutely no fossil fuels on the moon, so they would have to be brought up from the Earth along with all the other supplies needed. This would be a tremendous load to carry to the moon. Because of this, fossil fuels should not be considered a potential power source for the moon.

Solar power would seem a very viable solution to power the lunar base; however it is far from perfect. The amount of power that can be created using solar panels is not nearly enough to power any large scale operation. Solar power may be of use on low power requirement equipment or smaller operations. For the full base however, a larger source must be provided.

Another downside of solar power is that it only generates power when the sun is shining. Even though the moon has no cloudy days, the slow rotation of the moon causes long periods of darkness. The lunar "day" is approximately 709 hours (1), meaning that a lunar base would be in darkness for approximately 350 hours. This is clearly too long a time to be without power generation.

The other issue is the large area that would need to be covered with solar panels. To provide a decent amount of power requires placement of a very large

amount of panels that cover a large area, this requires a large effort to maintain these panels, and they must be protected from meteorites that occasionally hit the moon.

Overall, using solar power on a lunar base has too many problems to be used as the primary power source. Therefore, solar power is also not a viable solution to powering a lunar base. However, solar power could be used in tandem with another source to power low energy equipment of the base.

Nuclear fission is a third possible power supply. The amount of power a fission reactor is able to generate is enormous, for example the Indian Point nuclear power plant in Buchanan New York produced over 15 million Megawatt hours in 2003(2). This is enough power to run entire cities, so nuclear fission definitely generates enough power for a lunar base.

The major problem with nuclear fission on Earth is the radioactive materials that a reactor produces are dangerous and have to be contained properly. This would not be as big of an issue on the moon, since there is no life on the moon, the radioactive waste could be put almost anywhere with little danger. Indeed, the problem with fission on Earth is that no one wants to live near a reactor, but that is little to no problem on the moon, because there would only be the people on the moon base.

The one problem with using fission on the moon is that the uranium fuel must be brought up from the Earth. As far as scientists know, there is no supply of

uranium on the moon; therefore any fission reactor would require a supply of uranium to be brought up from Earth. This is not a big problem; however, if power can be generated from local materials, then that would be a much more desirable solution.

Taken as a whole, nuclear fission would provide serviceable power for the lunar base. However it still requires that an amount of uranium be transported to the moon, even if the reactor is a breeder reactor, some uranium must be brought from the Earth, plus material in order to store the radioactive waste must be transported as well, and a lot of time and effort must go into the proper disposal of the waste. Fission would work and may be used until a more sustainable power source is established.

Nuclear Fusion could be the solution. Unfortunately, fusion technology has not been fully developed. The physics behind the fusion reaction are known but have not been mastered. Successful fusion tests have been accomplished at the University of Wisconsin (3), as well as Princeton University (4). Further research is needed in fusion before it can be implemented.

However, experiments have shown that the potential energy produced by fusion power is immense. Already certain test reactors have produced over 1 million watts (5) while only being run for a short period of time. In fact, a reaction run for 10 milliseconds can create 10 MW of power. This is clearly enough power for a lunar base.

Fusion has another benefit, it is the only power source that has a local fuel source that can be used continuously. The lunar surface is covered with 3He, an isotope of regular helium that can be used in a fusion reaction. Fossil fuels and fission require the fuel be brought from Earth, and solar power only being generated during the lunar "day", but fusion power can be generated from local materials during day and night.

The other plus of fusion is that it is possible to run a fusion power plant with no pollutant or radioactive waste products. Fossil fuels produce large amounts of air pollution, fission creates radioactive waste, but fusion, like solar, only creates electricity. Therefore, due to these factors fusion is the most desirable solution to providing electricity to the lunar base.

Fusion power has been identified as the most desirable solution to providing electricity to the lunar base, a greater understanding of fusion is required. Fusion is the process of combining two smaller atoms into one larger atom. For example: fusing deuterium (D) and tritium (T) yields Helium (^{4}He) plus a neutron (n) and energy.

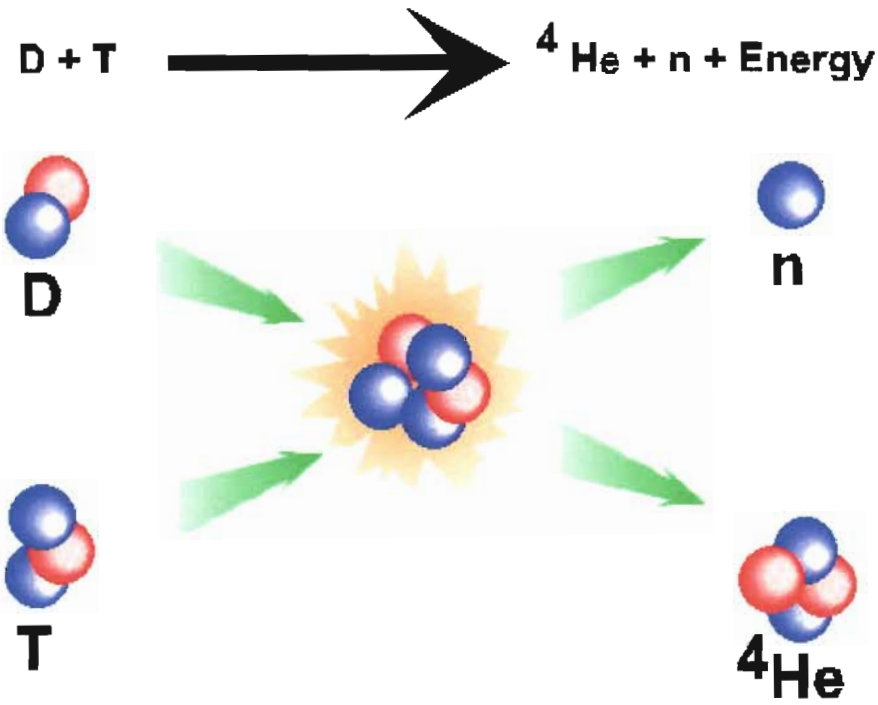

Figure 2 - The chemical makeup of the D+T Fusion reaction

In addition to the D+T reaction, there are three other major reactions, they are: the Deuterium (D) Deuterium (D) reaction, the Deuterium (D) Helium-3 (^{3}He) reaction and the Helium-3 (^{3}He) Helium-3 (^{3}He) reaction. Each reaction has its' own positives and negatives, and each produces energy in a slightly different way. One major distinction when it comes to fusion reactions is the amount of radiation released. Almost all fusion reactions release some amount of radiation but to varying degrees. However, all of the four reactions listed here produce substantially less radiation. Even the D+T reaction, which produces the most radiation out of the four listed, would only produce .1% of the radiation of a fission reactor in a 100 year timeframe. (5)

Another aspect of fusion reactions is the efficiency of the transfer to electrical power. If the high energy product of the reaction is a charged particle then direct conversion is used. Direct conversion uses "...a simple arrangement of charged electrodes..." (4) Direct conversion efficiencies have been as high as 86 %.(4) If the high energy product is a neutrally charged particle, than normal steam turbines must be used. This means lower efficiencies as well as the complicated design of having plumbing systems to move the water around the plant.

The amount of energy that a reaction produces must also be discussed, if one reaction produces more energy than another but has some negative effects, than these issues must be weighed. Also the relative abundance of the fuel source must be compared. Finally, a look into to relative safety of each reaction must be completed.

- 1) D + T → He-4 (3.5 MeV) + n (14.1 MeV)
- 2) D + D → T (1.01 MeV) + p (3.02 MeV) [0.50]
  → He-3 (0.82 MeV) + n (2.45 MeV) [0.50]
- 3) D + He3 → He-4 (3.6 MeV) + p (14.7 MeV)
- 4) He-3 +He-3 → He-4 + 2p (12.9 MeV)

The first reaction is the Deuterium+Tritium (D+T) reaction. The reason for this is that it is the simplest to produce. The D+T reaction also produces the

second most amount of energy of the four reactions at 17.6 MeV. However, the D+T reaction has quite a few problems associated with it. Tritium is a radioactive isotope of hydrogen that does not occur naturally. The amount of effort to safely use a radioactive fuel is something that should, if possible, be avoided. Another issue is the abundance of Deuterium and Tritium on the Earth. Deuterium naturally occurs in water, which there is a limited supply of on the moon. However, there has been no supply of Tritium found on the moon. The D+T reaction also produces high energy neutrons, which are radioactive, plus they require steam turbine conversion to electricity, which has lower efficiencies. This means that reactor must be shielded from radioactivity and that a system of pumping and collecting water must be worked into the design of the reactor. Finally, the worst case scenario for a D+T reactor would be no offsite fatalities which means that the only deaths would occur inside the actual reactor facility, however, when on the moon is could be devastating, and should be deemed extremely undesirable.

The Deuterium+Deuterium (D+D) reaction is the next reaction in order of difficulty to produce. However, the increased physical requirements to produce the reaction are rewarded with a substantially smaller energy output of 7.3 MeV. The actual benefit of this reaction is that it does not use tritium which is radioactive and not available on the moon. The D+D reaction does produce some neutrons, which means the issues of radioactivity and steam turbine conversion must be dealt with. The actual amount of Deuterium on the moon is unknown;

Deuterium naturally occurs in small concentrations in sea water. Deuterium concentrations in water are about 0.015 %(6). So, the actual amount is unknown as the amount of water on the moon is not precisely known. However, it is known that it will not be a large amount. The worst case scenario for a D+D reactor is also no offsite fatalities, which is an additional concern of this reaction.

The Deuterium+Helium-3 (D+^{3}He) reaction is the second most difficult reaction to produce, however it yields the highest amount of energy of the four reactions with 18.3 MeV. The other benefit of the D+^{3}He reaction is that it produces very few radioactive particles. This allows a "permanent first wall" (3) to be built, this means that the radiation levels are low enough that the shielding would be a one time installation that would never need to be replaced. Another plus is that Helium-3 is very abundant on the moon. The sun naturally emits Helium which is changed to Helium-3 by the solar winds, which then land on the moon; none exists on the Earth because of the Earth's atmosphere and magnetic shielding. The location of Helium-3 on the moon is the first few inches of the lunar soil with the concentrations being highest near the equator and lowest near the poles. This raises the issue of the water for the Deuterium being at the poles and the highest concentration of Helium-3 near the equator. However, this is still a better situation than the other fuel sources have presented. The D+^{3}He reaction releases charged particles, which allows direct conversion to electricity; this means the D+^{3}He reactor would have a much higher efficiency than the other reactions listed

so far. The worst case scenario for a D+^{3}He power plant is that no evacuation of the base would be required.

The final reaction discussed in this report is the ^{3}He+^{3}He reaction. This reaction is the hardest to maintain, in fact it has yet to be accomplished, but it is known to be possible. The ^{3}He+^{3}He reaction releases 12.9 MeV of energy, which is the third highest of the four reactions. The benefit of this reaction is that absolutely no radioactive particles are produced. This leads to a much simpler design that is much safer than the other reactions. As discussed above, ^{3}He is very abundant on the moon; there is over one million metric tons of ^{3}He on the lunar surface alone. This reaction also releases high-energy charged particles, which allow for direct conversion to electricity. One of the best benefits of a Helium-3+Helium-3 reactor is that it would be inherently safe, in the case of a complete failure; the plant would only shutdown, with no foreseeable complications.

After considering the positive and negative effects of the different fusion reactions, it becomes apparent that the Helium-3+Helium-3 fusion reactor would be the best option to provide power to the lunar base. One concern about using Helium-3 as a power source is accomplishing the physics of the reaction, to date, the D+T, D+D, and the D+^{3}He reactions have all been accomplished. However, it still take more energy to start and maintain the reaction than the reaction produces, but in the 20 or so years linear progress should bring about a net gain in energy from the reactions.

The way the reaction is done is by using a magnetic field to contain plasma of the fuel, which causes the ions of the plasma to fuse. The fuel is turned to plasma by heating it to extremely high temperatures. These temperatures are generally around one billion degrees Celsius, which sounds ridiculously high, but one must bear in mind that due to the density of a plasma, very little heat will raise its' temperature substantially.

The magnetic containment creates a sphere of plasma that is contained in a small volume so the temperature is kept very high. In that small volume the particles of the plasma are moving with very high energy and when two collide they fuse, releasing a tremendous amount of energy. In the case of the $^{3}He+^{3}He$ reactor this energy is released as high energy protons, which can be absorbed by a net of cathodes. The cathodes turn the protons directly into electrical energy with great efficiency. This design is much simpler than most other power plants because there is no coolant system, or heating water into steam to turn turbines. This simpler design is also of great importance to it's' use on the moon.

Figure 3 - Image of the D+3He reactor from the University of Wisconsin

The other benefits of the $^3He+^3He$ fusion reactor are that no radioactive particles are produced, there is a large supply of local fuel, however a way of gathering and processing the Helium-3 must be setup, and it is a more efficient way of generating power. In short, the $^3He+^3He$ reactor is a safe, clean, and powerful way of providing power to the moon, and as long as it is possible to gather enough it will most likely be the main source of electricity for lunar operations.

The Helium-3 is embedded in the first six inches of the lunar soil and can easily be extracted from the lunar crust (regolith). To extract the Helium-3 from the soil, the regolith must be heated to 1400 degrees Fahrenheit, which is a pretty modest number when it comes to industrial uses. Once that temperature is reached, the Helium-3 simply bubbles out of the regolith and can be gathered very easily. On Earth this would be a simple operation, on the moon however, this could be quite difficult, and will require quite an effort, however the ends justify the

means in this case as Helium-3 fusion power is definitely worth the effort involved in producing it.

The use of Helium-3 fusion power on the moon does not necessarily mean that it will be implemented on Earth. The use of Helium-3 fusion power will only be used on Earth if it is the most desirable fuel source for Earth. To examine the implications of fusion power on Earth, knowledge of the current state of the power industry is imperative.

In 2001, the United States generated 3.7 trillion kilowatt-hours. Of this 71.4 % was created using fossil fuels, 5.6 % by hydro-electric, 20.7 % by nuclear fission and 2.3 % by other power sources (2). In the next hundred years the world will be running low on fossil fuels and in the next 50 years the worlds supply of oil will be dwindling. Therefore, there is going to be a need for a new power supply. There are three major areas of power that will fill the void caused by the shortage of fossil fuels, they are: nuclear fission, nuclear fusion and "green" power sources such as hydro, solar, and wind power. There is already a strong movement against nuclear fission power in most countries in the world. This is obviously due to the negative environmental effects from radiation and the fear of a nuclear accident. Therefore, it is unlikely that large gains will take place in the fission market in the next fifty years. "Green" power sources will likely gain a larger percentage of power production, however, "green" power sources are dependant on the environment. That is, wind power plants can only go where it is windy. Solar power

plants can only be in sunny areas and where there is a large area to put the panels. Lastly, hydro power plants can only be installed on a waterfall. Due to this dependence on location, it is unlikely that "green" power can cover the absence of fossil fuels.

This hole in the power market leaves an opening for fusion power. Fusion power isn't limited to certain locations where the environment is just right, nor does it ruin the environment and cause a potentially dangerous area to live. Fusion power would be able to be setup anywhere without worry about safety concerns.

With fusion power taking a larger role in the power industry, the question becomes again, what type of reaction. The D+T reaction has large issues with the use of radioactive fuels and creation of radioactive products. The D+D reaction also has radiation issues, but also doesn't provide nearly as much power as the other reactions. The D+^{3}He is a possible solution because there is ample supply of Deuterium on Earth. Lastly, the ^{3}He+^{3}He reaction is also a good solution because it releases no radioactive particles.

The D+^{3}He reaction is quite viable because the amount of radiation is so low that it is almost of no concern. In Addition, this reaction produces the most amount of energy. It also has a higher energy yield than Helium-3+Helium-3, which means over all more power is produced. The ^{3}He+^{3}He reaction is also a good solution, the amount of energy created is still substantial but there is the added bonus of complete safety and no radiation issues.

In the end the distinction between the two reactions involving ^3He is small. Both produce very little or even no radiation, they both provide substantial energy, and use direct conversion so there plant designs would be very similar. The major problem with using these reactors on Earth is that there is very little ^3He on Earth. Therefore, for fusion power to be setup on Earth, the Helium-3 must be brought back from the moon. This is quite a large undertaking, but definitely attainable. With the massive amounts of supplies going up to the lunar base, and the base already mining Helium-3 for its' own power, it would be possible to send the extra Helium-3 back to Earth in the same spacecraft that the supplies were sent up in.

With Fusion power taking a larger role in global power market. The implications can simply be drawn out by viewing what the industry would look like after the fusion infrastructure is established. Cost of fusion power is estimated to be around the cost of nuclear fission power (5) which is one of the cheapest forms of energy. However, fusion has all the benefits of no radioactivity.

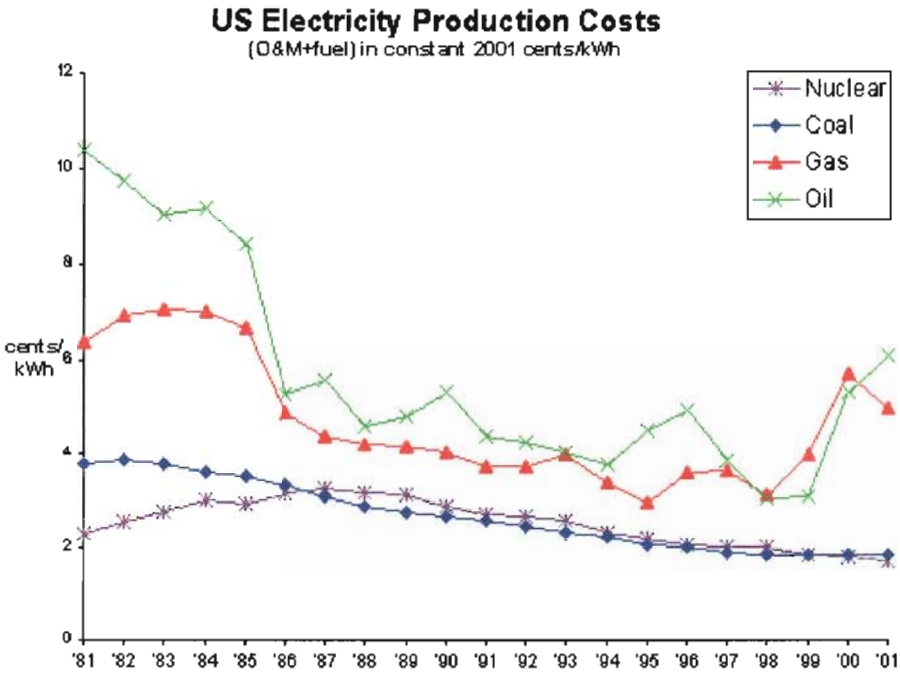

Figure 4 - The cost of electricity from various fuel sources. (7)

As this graph shows, fusion power would be one of the cheapest forms of power; this would bring change to the value of electricity. If electricity were cheaper, certain things that used up too much power could become more economically feasible.

The fact that fusion power is much safer than nuclear power or even fossil fuels allows power plants to be setup near the population without worry of possible hazards. Since fusion is not dependant on environment like the "green" power sources, a suitable location for a power plant is much easier to locate.

Unlike coal, oil, and natural gas, fusion power emits no emissions into the air, and unlike nuclear there are no radiation hazards. Even the "green" power plants require manipulating the environment. Solar requires large areas be cleared of trees and rocks, so the panels can be put into use. Hydro requires the building of a

dam which can wreak havoc on a river ecosystem. Whereas a Fusion power plant could run with little to no link to the outside environment, it runs as its' own self-contained system.

With the world's supply of fossil fuels growing ever smaller, a new power source will take its' place, and a strong fusion program could completely alleviate the dependency of fossil fuels. This also has geo-political ramifications as nations around the world find themselves competing more and more for oil. In the end the biggest implication of fusion as a power source is that it is a safe, clean, cheap, power source that could provide large amounts of power for a very long time.

However, there are issues that need to be resolved to move fusion power from the moon to the Earth. These issues revolve around the fact that there is little to no Helium-3 on the Earth. Therefore Helium-3 must be brought back from the moon. This requires a large infrastructure similar to that of the oil industry but would be even larger due to the greater difficulty of getting the materials. In addition to this, the high initial cost of setting up and running a fusion reactor is something that requires consideration. The reactor itself is a very complex device and running it requires a strong technical understanding. This would require a stronger educational background than current power plants require. All of these factors cost a tremendous amount of money that must be invested for fusion to reach its' potential as a power source.

Ultimately the impact of fusion power depends on how quickly it develops, and how quickly the Earth uses up its' source of fossil fuels. The faster it develops and the earlier it is needed the larger the impact will be. Eventually though, the Earth's supply of fossil fuels will run out and a new fuel source must be found, and fusion seems like a very strong candidate.

Results: Bio-technology

For this part of the study on the social impact of the second moon race, literature on microgravity and the body was required; also information on diseases relating to aging had to be researched. This is such an up and coming area of research that nearly all of the sources came from the internet or periodicals. For this section there are many aspects that could be looked at regarding the human body, but only the two that the most progress has been made on will be examined in detail here. These issues were bone and muscle/blood deterioration. To be able to discuss these areas, basic biology is needed to explain the science behind blood, bone, and fluid, information on that was also researched. The issues raised by low gravity environments have a fairly direct correlation with diseases on Earth. Hence, facts about the diseases most analogous to the effects of microgravity could be researched in some detail. Medical advances to help combat the effects of microgravity are of direct interest to NASA so, a lot of information was found through NASA and its partners in the study of these problems. With all of this data and information combined, some of solid ideas emerged as the basis of predictions, as to what impact NASA and its associated research groups are likely to have on the society on Earth as a result of the new moon race, and the need to sustain astronauts in space for long duration missions.

When man embarks once again to travel to the moon with plans to inhabit it, he will be facing many dangers. Besides the dangers of space itself, possible

accidents with material, or mechanical breakdown, he faces a challenge that may be easy to overlook. This challenge is how to overcome what effects space will have on his body. Our bodies were designed specifically for Earth and its gravity, when entering a micro gravity environment many features of Earth that the body usually faces (forces pressures etc.) are removed creating surprisingly dangerous results. In this environment our bodies are affected in a way that is akin to an accelerated aging process. The areas of key interest include nutrition, radiation, space sickness, muscle, bone, psychological issues, immune system deficiencies, and balance issues.

For NASA these key issues that must be addressed as priority issues. In order for missions to be possible, much less productive, astronauts must be able to spend a reasonably long period of time in space in order to mine, train, and perform experiments on the moon so that they can use the knowledge they gain to eventually make their way to Mars. It would be very inefficient and costly to have an astronaut only be able to spend a few months in space. Projects would be started and worked on by many people, but not by the same people at the same time. This would lead to oversights, execution lapses, and the like that could be fatal mistakes in the unforgiving lunar environment continuity problems of all kinds and high costs would stall the space initiative.

By solving the health problems faced by the astronauts, NASA and project centers funded by NASA will have great social impacts on the lives of people affected by similar ailments on Earth. In the following sections the major health

problems faced by astronauts will be examined. Also described are the methods in development to deal with or overcome these issues, and how once in place could change the way certain people are able to live, allowing for a healthier and longer life.

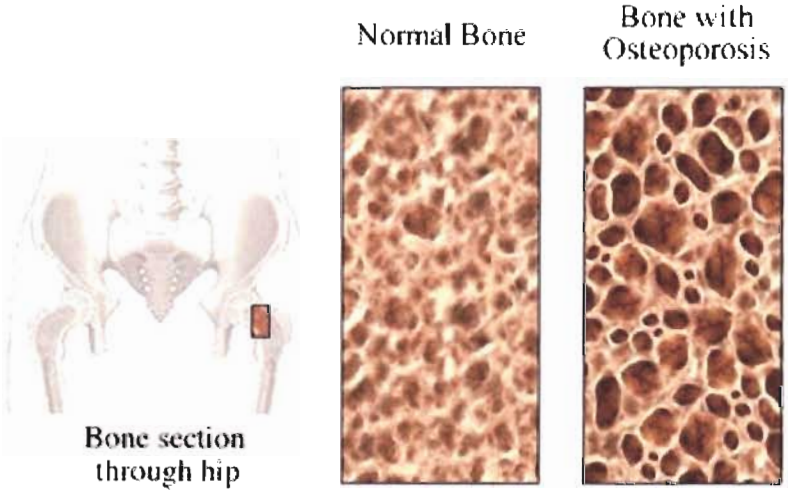

Figure 5 - The left bone is normal and healthy, whereas the bone on the right has bone deficiency

One of the biggest dangers faced by our men and women by spending time in microgravity is bone loss. When the astronauts are living on the Moon or on space stations (microgravity) their bones do not experience what is known as mechanical strain, which "tell" the bone cells (osteyocytes) that there needs to be production of new cells. Without gravity these cells "think" there is unneeded bone present and it is receiving nutrients that should be sent to other areas in the body. This in turn results in cells known as osteoclasts to secrete acids and enzymes to dismantle the bones by eating away at them, creating cavities, weakening them and putting calcium into the bloodstream. As a result of the bone being broken down,

calcium is deposited into the blood stream, which creates a much larger concentration in the blood than normal, the body must remove it, so in turn would pass large calcium stones thru the urine and (painfully) out of the body. Some general estimates state that on average of "1 to 2 percent per month loss is an estimate of bone loss" and "certain individuals on six month flights have lost as much as 20 percent of bone mass throughout their lower extremities." (9) A research team from the University of California San Francisco (UCSF) and Baylor College of Medicine, Houston, with a CT scanning device, took images of the Pelvic bone of the space station inhabitants before and after of the stay in the microgravity environment, to determine changes in the bone density. After looking at the results the team from USCF found that on average, the 14 members Station crew lost interior bone at a rate of 2.2 to 2.7 percent for each month in space and outer bone at a rate of 1.6 to 1.7 percent per month. Also from the study they found on average, the Station crew lost vertebral bone at a rate of 0.8 to 0.9 percent per month. (13)

As one can see from the affects of microgravity on bone, for humans to be able to work and live is space for a period of time, bone loss must be resolved. A big problem with bone loss and its recovery is the fact that it varies greatly in individuals, because of genetic backgrounds. For example, in a study on a group from Mir, two American astronauts who were in space a little over four months were found to have deficits in bone mass for more than two years after their tour on

MIR ended. In contrast other members recovered their lost mass in as little as six months after arrival home. (8) So now in order to treat this, the variations faced by individuals must be overcome. Too much "treatment" or too "little" treatment can be problematic. Another problem to address is that the method use to treat the astronauts can not have adverse affects to their ability to perform his or her tasks. When performing experiments requiring precision, wearing bulky gloves could result in measurement errors. In development and testing are methods that are mechanically and biologically driven to counter the effects of the bone loss.

Figure 6- An astronaut on an exercise unit

Mechanically, NASA has always had an exercise regimen to keep the astronaut healthy. Some of the items used by astronauts include stationary bikes, a treadmill (quite cumbersome in that the astronaut must be strapped to it) and resistive exercises that apply supply loading forces to the body. These exercise machines and equipment can take up space in the crew area that could be used for

more important things such as more space for experiments or more living quarters, they can be cumbersome, and astronauts still suffer from the bone loss.

Another idea is to use specialized plates, which the astronaut would stand on for 15 minutes a day, which vibrates at 90 Hz sending oscillations through the bones. These oscillations simulate tiny stresses, "tricking" the body to think it is experiencing Earth stresses and continues with bone growth activity and not bone eating activity. In a study with rats, spending 10 minutes each day on vibration plates upheld near-normal bone formation rates in rats that were not allowed to perform weight bearing activities on their back legs during the remainder of the day. A second group (control) of rats that had their back legs hung up all day exhibited a severe decline in bone rate formation. It was roughly down by 92%. Another group (experimental) spent 10 minutes a day in weight bearing activities, without the vibration plate being used on them, and even with just exercise had reduced bone formation of 61% less. (25)

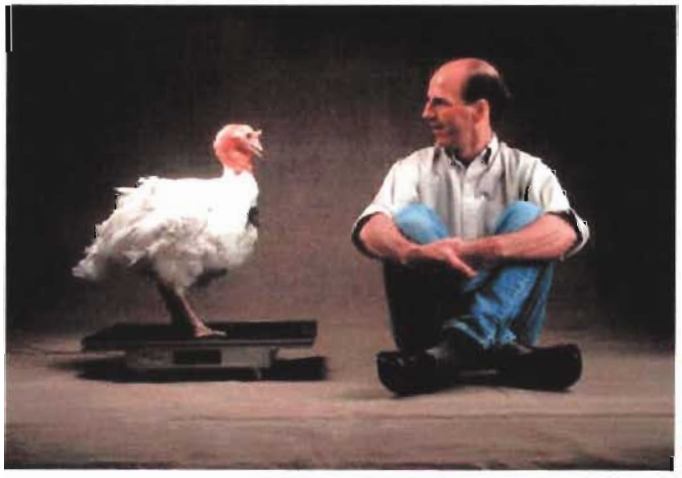

Figure 7- A turkey being tested on a vibration plate.

Another method to treat this problem is not by working "outside" the problem but "inside" the problem. As mentioned above, mechanical treatment is not as effective as one would hope, but combined with biological treatments it is potentially a winning combination. As the astronaut exercises the blood flow increases, leading to a more effective depositing the drugs in the crucial area of the body. (12)One peptide that looks promising is known as glucose-dependent insulinotropic peptide. This peptide is naturally secreted in the small intestine by endocrine cells. This peptide attaches to bone when receptors it recognizes are put into the bone, by the gut during the digestion process. This peptide once in the bone triggers osteoblast activity to intensify while causing osteoclastic activity to diminish. If these peptides were altered and delivered in a way either thru diet or drug to make it very effective to reverse the bone loss, Astronauts could spend more effective periods of time in space. (9) Another option scientists are looking at is a precursor enzyme that is important to the creation of osteoblast cells. This enzyme is known as "creatine kinase-B". What scientists are doing is looking at how this enzyme in particular reacts to microgravity and trying to work with the molecules to possibly make them "immune" to microgravity. The idea is to alter them such that they will produce the cells such that result in continued growth even though the body is not feeling gravity. (9) Another medicine that is being tested and worked with is a drug known as alendronate. This Drug is already in use for patients with osteoporosis, but it takes a long time to see results on Earth.

Since it will be tried/experimented through microgravity, the results will be known in much less time and the cycles of trial and error accelerated. We believe that research acceleration possibility, combined with and ongoing new resources will provide important results. The main function of this drug is that when it is put into the body it seeks out and destroys osteoclasts which are the main culprit for bone eating affects. (17)

Today In the United States alone there are roughly 10 million men and women with osteoporosis along with 34 million that have low bone mass leaving them open to osteoporosis. Having this disease has lead, to over 1.5 million fractures and an astonishing 700,000 being vertebral. As a result of the fractures large numbers of patients are permanently affected, either requiring constant care or being immobile. In 2001 the estimated costs associated with osteoporosis was approximately 47 million dollars a day. The numbers of people with this affliction and the cost to treat it is "astronomical". In NASA's attempt to overcome the dangers faced by astronauts they will inadvertently have a huge impact on society. Finding a drug and exercise method to counter Osteoporosis will lead to taxpayers saving billions of dollars and will create a longer healthier life for the aging population.

Another big issue that needs to be addressed is muscle and blood flow. Both of these systems are much related due to the fact that muscles move the blood around the body and blood provides nutrients to the muscles, so they must be looked at in unison. Because the human body was designed to work with the gravity found on Earth, blood and muscle are affected greatly. Gravity on Earth is in a downward motion (9.8 m/s^2) and therefore naturally keeps things from rising. In the human body the natural gradient, by the heart, pushes blood upwards towards the brain so that it does not pool in the feet. Because of the pressure the walls of the blood vessel, they are much larger to deal with the forces of gravity. This will be important in terms of muscle atrophy and weakening, discussed later. In microgravity the natural gradient is not present, and fluids pool towards the upper portion of the torso. It takes time just to read but after awhile the human body can function.

Figure 8- An astronaut before and during space flight with fluid accumulation in the head

One study that was done on a primate in microgravity resulted in the primate developing rapid initial decrease in heart rate and a further lowering of heart rate while remaining in microgravity. Another large change was in the primates arterial pulse pressure, which increased, producing an adjustment in the shift of fluids to the head. This could be the result of mechanisms designed to provide the proper amount of oxygen to the brain. (37)

On the other hand there do seem to be limits to what primate equilibrium maintenance mechanism can handle. The scientists involved in this study report that the heart rate and blood pressure did not show any evidence of stabilization by the end of the 5 day mission. (37) The resulting extremely low blood pressure could have dangerous effects, in the case of astronauts spending long periods of time in space. This could include anything from exerting themselves to the point where they need higher levels of oxygen and because of the extremely low blood pressure, it won't be delivered and they could pass out at the helm of a mining machine or other equipment. Another concern is that if this issue is not addressed, the havoc of returning to Earth and facing its gravity again could wreak on the circulatory system. Will it be able to adjust rapidly enough to our normal pressures or will the returning (hero) astronaut pass out or possibly die of complications. Another concern is with blood and the actual loss of it in space. In a study on Astronauts on board Skylab, it was discovered that they suffered Red blood cell mass loss that averaged 14% on a 28 day mission, 12.3% on a 59 day mission, and

6.8% on an 84 day mission. The non cellular portion of the blood (plasma) was lost at an average of 10% on the 59 day mission and 16% on the 84 day mission. (10)

The underlying issue is related to muscles since their nutrient delivery system (blood) is subject to misread signals similar to those resulting in the bone problems described earlier. Microgravity "tricks" the biofeedback system in the body such that it believes it does not require the mass of blood and muscle has built up while on Earth. Research has shown that as much as 5 percent of muscle mass is lost in a single week in microgravity up to around 20 percent as more time is spent. The main muscles areas that are affected are ones that fight the affects of gravity on Earth, which include spine, calve, and hamstring muscles. With weakened muscles the astronauts would eventually have great difficulty performing laborious tasks that are related to mining work and other jobs, on the Moon or Mars after being weightless getting there (16) Upon their arrival back to Earth they would basically be weakened to near vegetable levels and if the damage is too great due to a large time spent in microgravity, they could be bed ridden. When Cosmonauts Berezovoi and Lebelov returned home after spending 211 days on board Salyut 7, they could barely walk, and required weeks of intensive rehabilitation to get their bodies back in shape. (10) Another serious issue that needs to be examined is what was mentioned earlier about vessel walls and blood delivery. Since the walls associated with blood pressures are made by a large part of muscle, when muscle loss sets in they may become weaker over time. This could become a huge issue

when the astronaut returns to an environment of gravity. These weakened walls on Earth could very well rupture and cause internal bleeding and the astronaut could die of that before they could be rehabilitated. We also must remember that the heart is a muscle and because it will not need to be pumping as much blood due to microgravity it will atrophy over time. It is pretty clear what could happen when a return to gravity occurs and an atrophied heart had a massively increased load placed on it.

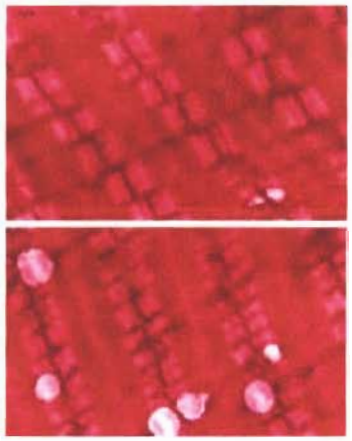

Figure 9- Muscle before and after space flight, the white areas show atrophy.

It is clear that NASA must address these issues. Astronauts may be able to recover after short stints in space, but just from the condition of Cosmonauts Berezovoi and Lebelov bodies after 211 days, damage will most likely be more severe due to the required time spent in inhabiting the Moon base. One method that has been used in space stations to fight muscle degradation is by physical activity. Similar to the bone problems, a load needs to be placed on the system exercise equipment such as Bicycles and treadmills are useful in addressing both

problems. The drawback to performing this method to combat atrophy is that it only slows the process, it doesn't halt it. This is fine for short stints in outer space, but with the time needed to be spent on the Moon by the astronauts the lessened atrophy rate do to exercise will add up over time.

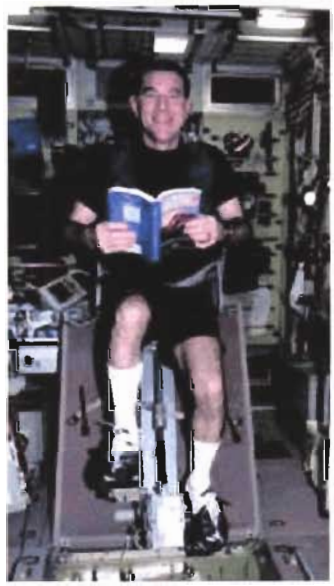

Figure 10 -An Astronaut working on muscle conditioning.

Another idea that is in the works is "space boots", which feel as if a reaction force is applied to the feet. This Force makes use of all of the muscles, found in the feet and lower part of the body, used to balance the human so they can stand upright. Associate Professor Chuck Layne (University of Houston) designed these boots which use pneumatic pressure that simulates muscle contractions that are very similar to what a person would feel on Earth. So even when not standing (sitting or lying) the astronaut is still using the muscles most likely to atrophy. Once again this decreases the atrophy rate but is not a cure. (12) Besides outside

mechanical options other drug and biological idea and methods are being looked at (similar to that of bones).

One promising study involved working with amino acids. Amino acids are the building blocks of proteins. About 20 different amino acids are commonly used by cells to make proteins which are complex molecules made by genes, that give structure to our organs, bones and muscles. They are often called the building blocks of tissues. Scientists at National Space Biomedical Research Institute conducted experiments by using forced bed rest to simulate muscle loss. It was discovered that in a 28 day experiment patients giving certain amino acid supplements had much less loss in muscle mass. (26)

Another option that NASA is looking at is gene therapy with insulin-like growth factor 1 (IGF-1). This would allow muscles that are not being strained (due to microgravity) to avoid wasting away and just continue to live and grow until they are worn out. The best way to deliver IGF-1 is through gene-therapy. Gene therapy is a process that involves altering the genetic composition of cells for the treatment or prevention of disease and in this case muscle atrophy. The Gene therapy procedure involves the DNA sequence for the insulin-like growth factor being inserted into a retrovirus that is replication-deficient. Retroviruses carry RNA rather than DNA, but this type of virus cannot trigger replication of its own RNA in a host cell. Instead, it carries the genetic material of an outside DNA for

replication. Then the engineered retrovirus is positioned into the cells of muscle tissue to allow the outside DNA to integrate into those muscle cells and become stable. The reason why Gene therapy would be so useful in this case is because (IGF-1) has a very short half life, since it degrades in only a few hours and would have to be injected in very large quantities leading to high concentrations, which will probably have some unwanted side affects. (16)

Many good things can happen for people of Earth From based on all of the research now being done now relating to the astronauts' muscle and blood levels. Implementing new and improved exercise methods and other mechanical devices ("space boots") have already begun to show promising results in "slowing down" space based muscle and bone atrophy. Clearly the real "fix" to the problem involves intervention into the body itself (drugs or therapy) and this seems to be on the way. Numerous people around the world, with a variety of ailments, suffer from the effects of muscle atrophy afflictions. People who are bed ridden are most likely to be afflicted by the more serious affects of muscle wasting, but there are many more possible sources of this problem. Patients with strokes, spinal cord injuries, nerve injuries, osteoarthritis, rheumatoid arthritis, prolonged corticosteroid therapy, diabetic neuropathy, burn victims, poliomyletis, Lou Gehrig's disease Guillian-Barre syndrome, muscular dystrophy, myotonia, congenital myotonic dystrophy, myopathy, and AIDS all suffer from this debilitating problem. Imagine the implications if muscle atrophy and its effects could be eliminated, as a spinoff

of the race back to the Moon. New therapies, would result from efforts to maintain the health and vitality of Astronauts and billions of people would start to be able to live a without needing help with mobility (wheel chair etc.). It is conceivable that billions of dollars a year could be saved every day by taxpayers. Billions more also would be saved by the aging populations paying higher health insurance premiums to cover the needs of age related debilitation. Consider what these freed up resources could mean if used to address other problems of the ailing aged. Once the problems related to the accelerated aging process are solved, astronauts will be able to fulfill of their missions to the Moon and beyond, but beyond that we will have entered a new era in understanding and treating, maintaining and stimulating the human body in the face of the aging process.

The Social implications of the new Moon race especially in the biological and health areas are potentially huge gains in the vigor and vitality of the aged, now afflicted by a number of vexing physical problems. This Moon race, unlike the last one, will have some extremely important effects that could very well change the level and quality of life for the human race. Everything from the elderly with osteoporosis and patients immobilized from a fall leading to their muscles in atrophy, could have a new shot at life by having their aging process slowed or even reversed. Having these experiments completed and the resulting treatments put into effect quickly, other patients could receive proactive treatments. This is especially true for groups of individuals that are prone to certain diseases.

Results: Space Industry

The space industry is a relatively new industry. It began in the mid twentieth century after the invention of the liquid fueled rocket. The first big boost it got was the (first) space race in the 1960's when there was a growing interest in space. The technical foundation laid in World War II and the Cold War to follow with missile technology was used to gain access to space and reach the Moon. The space industry has seen several changes since then and now satellites are an integral part of the Earth's economy. What has not happened is profitable manned space activity. If a base is created on the moon, the space industry will be revitalized and what we think of now as the space infrastructure will get a complete makeover as manned space activity is moved back to the center of things.

This section of the report differs from the previous sections. It is a speculative analysis on what will happen to the space industry in the future. There is little scholarship published on this topic despite the large science fiction literature. Therefore it was difficult to find sources the dealt with the Earthly aspect of Mankind's venture into space. The idea of the space platform and Moon base came from other WPI student project teams that are working on the space policy initiative. Other than that, the ideas in the following pages came from either a brainstorming activity within our group to logically determine what will happen, or using various websites that talk about the future of space travel.

Originally, this section started as a forecast of what will happen to the Space Coast in Cape Canaveral, Florida. However, we soon realized this was not a broad enough topic and with the technologies that might exist in fifty years, Cape Canaveral was unlikely to be a hub for space travel anymore as space around the base was too limited. Experiments using large ships in the ocean were being performed by the American aerospace companies.

That would bring new life to the several seaports, but not Cape Canaveral. If there is to be a sizeable moon base, the need for a practically new space infrastructure must be faced squarely. This infrastructure will have to supply the moon bases with transportation to and from the Earth as well as equipment, food and materials needed for construction and life support on the moon. Establishing enough agriculture on the Moon to sustain the population there will be the challenge. Food will not be exported except perhaps to nearby space stations. It will however become a re-supply outpost of some significance. The new space industry will thus lead to new jobs and a growth primarily in the Earth's economy. Growth in the space industry however, will not happen overnight as there will have to be some way of paying for all of the initial setup costs of making the moon habitable.

Presently, manned space is not profitable and this will have to change before a permanent moon base can be established. The ESA on the other hand, does make a profit to pour back into the development of new capabilities when they launch

satellites commercially. However, this Low Earth Orbit activity is still not nearly enough money to make manned activity affordable, much less to create a moon base. In fiscal year 2001, with a budget of 14.285 billion dollars, NASA spent around 5.46 billion dollars for Human Space Flight (28). This number would skyrocket, increasing by at least five times, if there was an attempt to set up a moon base for even ten people today with current technology, since as of now there is no compensating income from manned space flights. There must be some way of getting the space market up and running. There are lots of ways this is possible and these include: space tourism, space burial services, military outposts and scientific research centers. However it looks like the concept of a space platform might be the way to overcome the lack of profit from space and give the manned space industry the kick-off it needs to get a positive cash flow.

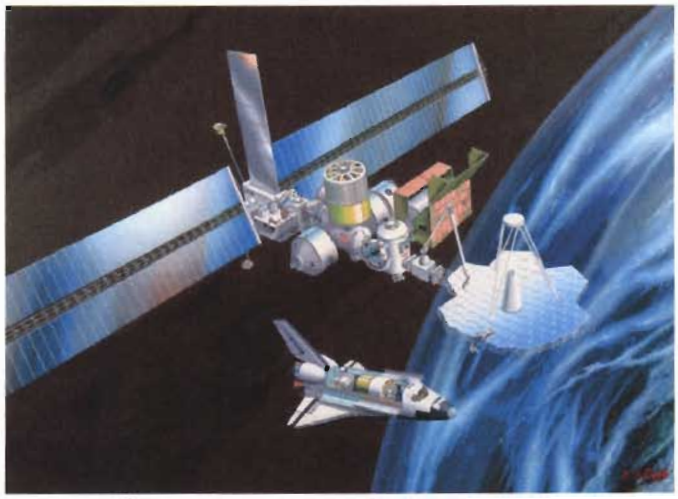

Figure 11- Rendition of a space platform

The idea of a space platform has been around for awhile but has never become a reality. Instead of having a small hand-crafted satellite for every instrument for communications or Earth sensing that is in space, as is the case right now, the space platform would house several standard but interchangeable instruments. It would basically be a platform with a docking bay from which people could service these instruments. The whole reason for this is because at the present, if the instrument on a satellite begins to fail and needs to be replaced or is outdated and needs to be upgraded the whole satellite must be abandoned and not used becoming space debris until it eventually burns up in the Earth's atmosphere. This process is economical only until one can repair, replace or upgrade individual instruments in the overall instrument package. The space platform would change this situation because it would be "man-tended" meaning that if an instrument were to fail or need upgrading, a human would go up to space and make the necessary repairs as well as do a checkup on all of the other equipment on that

platform. The array of instruments would be able to evolve to meet changing client requirements.

At the outset of the industry shift, the platform will not have a pressurized cabin in which astronauts can live. There will only be a docking bay for them to dock to the platform from the vehicle in which they arrive. However, as the program advances and there are more and more instruments attached to larger and larger space platforms, additions can be made where temporary living quarters (life boat facilities) can be attached to those who come to do equipment upgrades and later more complex experiments. In this case it would basically evolve into a small space station. (30)

In order to get a program such as this one started, a couple of things are going to need to be worked out. First, since this will be a man tended platform, there is a need for cheap, small and reusable manned space vehicles and second there will be a need for cheap heavy lift unmanned capability to get the basic structure up in the first place.

With the need for a manned space vehicle comes a big problem for the American space program. At the present, the seven man space shuttle designed to build a full scale space station is being phased out. It will be touch and go whether the fleet survives long enough to finish the space station since now two of the original five are lost. A new, much simpler and cheaper design, needs to be implemented before a project such as the space platform can commence with U.S.

equipment. There is no new design under development by NASA, though the private sector has been developing some interesting ways to do sub orbital hops which may help NASA. Other countries have been developing the technology for a program like the space platform. The ESA's Aurora project is to produce a two man shuttle that would be launched using the standard Ariane 5 booster. Also, the Japanese HOPE program is a slightly larger version of the ESA's project. The Russian and Chinese also have programs named Soyuz and Sensor, respectively, which would be able to lift three to five astronauts up to space.

Second, there will be a need for cheap unmanned capability. With an unmanned space vehicle needing a failure rating of only about ninety percent and a manned mission needing at least ninety nine percent, the cost of the extra nine percent is immense. Therefore, the unmanned vehicles are essential to lowering the cost of the program and thus allowing more companies to be able to afford to participate in the move to space platforms. The USA's shuttle, with a big cargo bay to carry bulk structural components into space with all that overhead and cost is just irrational and will not be repeated. These unmanned missions will be used to bring the platform itself (and possibly the instruments) up into orbit. The question is whether a robot that can attach the larger instruments to the platform is possible. However, the human presence and backup during initial assembly is crucial. This, in and of itself, will start the ball rolling for the space industry but the later

complex repair and reconfiguration would be done by human crews visiting on a regular schedule.

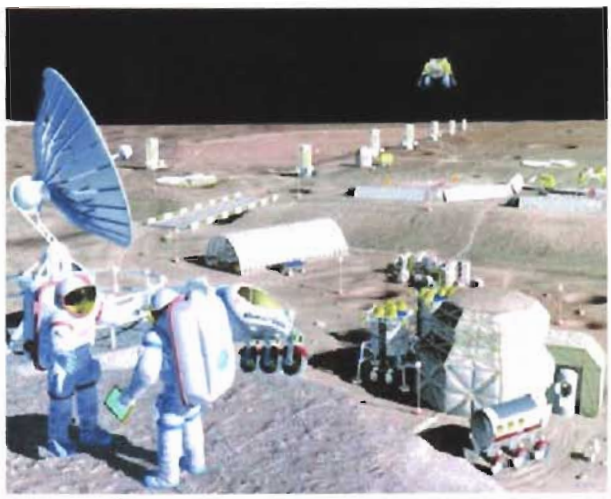

Figure 12- Rendition of a moon base

It is on this foundation of platforms and one real space station that the infrastructure for a moon base would be built. Men in space will be there for a cost effective reason and do more and more. The United States landed on the Moon in 1969 to end the first space race between Russia and the US. Since then few unmanned space missions have gone back to the moon to study or live there. However there has been considerable unmanned activity, including a robotic rock sample retrieval mission by the Russians. Hence, not much has been accomplished with regards to habitation on the Moon and manned transportation on the Moon, but it has been explored thoroughly and we now know where the water is: at the poles. That is one thing you want to be able to get locally. Still, there will have to be new technology in the field of rocketry and a suitable method of constant

transportation to and from the Moon if even a self sustaining base is to be built there, much less one that functions as a trade depot and spaceport.

There are basically two reasons for the establishment of a Moon base. The first reason for a moon base is for mining of Helium-3 and other precious minerals and deposits not found on Earth. The second is to use the Moon base as a place to practice for a mission to Mars. Both of these reasons to go to the Moon will require a substantial infrastructure on Earth to supply these missions. However, the mining option is the daunting one that requires a huge buildup, yet it is also the one that could pay for itself.

Mining on the moon will be essential to any kind of a sustainable moon base, even one that is for "practice." While there is platinum and other rare metals on the moon, the biggest export from the Moon will be for Helium-3 for fusion, which is what the Earth wants but does not have. The Helium-3 will be mined from the surface of the moon where it is located in the first meter or so down from the surface (mostly in the first six inches) and therefore mining machinery will have to be either fully assembled and delivered to the moon, or it will have to be delivered in pieces and then assembled on the lunar surface where it would be used for shallow "strip" mining. In order to obtain Helium-3 from the lunar surface, the soil will need to be heated to approximately 1400 degrees Fahrenheit. (35) One does not want to heat up the whole lunar surface, so the Helium rich soil will need to be transported to a processing center to heat the soil and capture the Helium-3 gas as

it is released. This could prove to be a very daunting task considering no one has ever done anything of this magnitude in microgravity and the movement of gases may be unpredictable at one-sixth Earth's gravity.

If the main reason for having a moon base is for a Helium-3 trade between the Moon and Earth the crux of it will be the ability to move large tanks of compressed gas back to Earth at low cost. They will probably return full of CO_2 which would be needed to support photosynthetic agriculture on the Moon. As discussed above, Helium-3 is excellent as a source of fuel for nuclear fusion. The question is, why build this big infrastructure on Earth just for Helium-3 when the Earth has Deuterium locally in the oceans? It has been predicted that about twenty-five metric tonnes of Helium 3 would power the United States for 1 year. With an estimated 1.1 million metric tonnes of Helium-3 on the Moon, the Helium-3 present on the surface of the Moon would power the United States, at its current power needs for 4,400 years. There is ten times more energy in the Helium 3 on the Moon than in all the economically recoverable coal, oil, and natural gas on Earth. It is estimated that a metric tonne of Helium-3 would be worth around 1 billion current dollars if it could be converted to electrical energy. (3) In 2004, the cost of a barrel of crude oil reached fifty dollars. (36) In the same sense, the energy cost of Helium 3 is equivalent to oil at seven dollars per barrel. (3) The impact of a fuel source this cheap on the Earth would be remarkable.

No one can predict what is going to happen to the population of Earth once the supply of oil runs out and no equally cheap alternative is available. Various estimates suggest this is going to occur in fifty to seventy years depending on rate of consumption. The demand for fossil fuel is extraordinary and coal is not able to be readily substituted for many uses to which oil is currently used. There is the gasoline used for automobiles that transport citizens to work, school, etc. as well as transporting cargo. There is also the airplane fuel to move both people and cargo far distances in a short amount of time. Just as important is the natural gas that is used to heat homes, but we have heated with coal in the past, and could again. Electrical generation from coal or nuclear fission is also possible. The problem is transportation. Aside from coal fired and electrical trains and trolleys, these fuel sources are not really adapted to land transportation.

The transportation industry will be greatly changed once the world is out of oil. Automobiles will most likely be either completely electric, hybrid, fuel cell, or hydrogen fueled. There will most likely be increased interest in rail transportation especially to move freight. However, there will probably not be any change in the aviation industry's need for liquid fuel. Coal will have to be converted into something like oil and then to aviation fuel.

The airplanes of tomorrow will most likely not have changed. It may be possible for them to be more fuel efficient, but it takes a lot of energy to lift a plane into the air. No one seems to be talking about a solar or nuclear electric

airplane. There is no alternative technology that looks like it might be working in fifty years at any rate. Therefore, in the future, planes will need to have a reserve of oil to keep in operation or else they will not be able to operate without very expensive coal processing plants.

Automobiles will have the greatest change because of the lack of gasoline. There is currently no cheap way to replace the gas that runs the cars. New and upcoming technologies are starting to emerge but these basically involve electrifying the cars and that means a battery breakthrough is needed. Success on that front would massively increase the demand for electricity and hence the significance of fusion reactor technology. In the short run we need to extend oil supply to buy time. A hybrid car which uses both batteries and a gasoline engine that only runs when needed is the most promising way to do that which is now on the market. Fuel cells and hydrogen as a source of energy may be an option in twenty to twenty-five years. Farther out in time, one may be able to deliver electricity to cars as needed (electrify roads) and have cars run off of that much the way electrical trains operate. The safety challenges of that technology are daunting, so we think batteries are the most likely development to emerge in an incremented way.

With the drastic change in automobiles, it may no longer be economical to transport long haul cargo by tractor trailers. If so, the rail industry will have to handle the long hauls with trucks just taking things from the rail depots. Just as

with cars, the rails would be able to be electrified such that they do not need to run off of diesel oil, which will scarcely exist in fifty years. If cars and tracks are going to be electrified, where is this electricity going to come from?

Electricity is used to power everything from homes to the computers that, today, help run the economy. Electricity is a vital form of energy and the sources of electricity today seem to be mostly dependent on fossil fuels. The main sources for electricity are fossil fuels which include: coal, oil and natural gas, renewable energy resources which include: solar, wind, waterfalls and biomass, which is essentially burning waste from agriculture or forestry. Some organic animal waste can be used to produce methane. The last source is nuclear fission. This list shows that, if the source for oil and natural gas run out, the remaining ones do not look too appealing.

There is still a supply of coal left on the Earth which can be used for a century or two while a new "ultimate" source of power is established. However, coal is definitely not something that should be used for an extended period of time because it pollutes the air, exacerbates the Greenhouse Effect and is difficult to transport. The environment is bad enough as it is today. Imagine what it will be like in fifty years when the oil is running out, the clean burning Anthracite coal is gone and the softer Bituminous coal has to run the economy. The Earth does not need soft coal to be a main source of power. Another alternative that is less polluting would be welcome. Also, unlike oil and natural gas, coal cannot be transported far by

truck or pipeline. The only proven method of transportation for coal is by train, though coal slurry lines have been suggested as a way to "pipe" coal in a manner similar to oil. There are drawbacks to mixing however, which include coal dust and water when you want to burn it later.

The other sources of electricity, as stated above, are also not a very good option. Nuclear fission produces radioactivity which is definitely not desirable. Sources such as wind, solar, water and biomass would just not produce enough electricity to make it a feasible option. Therefore the only good option is nuclear fusion.

The lunar surface is very desolate and has no growing vegetation. Because of this, supplies are essential to something like a Moon base. There will need to be some form of supply line that delivers essential goods to the base. Without this supply line, a base would not be able to exist unless there is some advancement in growing plants in microgravity in order to become self-sustaining. Thus, an unmanned ship would be used for this because the supplies do not need to get to the base quickly like the astronauts do, the ship can go very slow, and slow means less expensive which is essential in this kind of business.

The Helium-3 that the Moon is providing needs to, in some way, travel to Earth. If there is a supply line that runs to the moon, then the smartest thing to do would be to use the same ship that delivered the goods to the Moon, to send the

Helium-3 to the Earth. This way, the same ship can be re-used and the transportation of goods would be less expensive. Again, as with the supplies, the Helium-3 does not need to rush to the Earth therefore it can take a greater amount of time to reach the Earth.

A new infrastructure to support the import of Helium-3 would have to be created on the Earth. There are many options with which this can happen. Only one spaceport is needed to accept the incoming Helium-3. This worldwide distribution center would mean that the Helium-3 would have to be transported by land and sea to the countries that need it which might prove to be not very economical. This leads to the second option of having five or so spaceports to accept the Helium-3. This would mean that the Helium-3 would not have to move as far and therefore would be more economical.

The oil that is being used today is mostly coming from countries that do not need the oil to run their economy. This means that the countries that have the greatest demand for oil are importing most, if not all, of their supply of oil from foreign lands and these countries do not get the oil from one area. The oil comes in pockets and is becoming increasing difficult to find. If the Helium-3 industry was started, there could be one location for the Helium-3 and the trade could be regulated much more efficiently.

The other reason to set up a Moon base is to have it as a practice base for a mission to Mars. NASA's ultimate goal is to set up a sustainable base on Mars. It would not be in NASA's best interest to attempt a Mars base without a lunar base first. A lunar base for the United States would definitely be a lot different than a mining base for Helium-3. There would be a lot more scientific experiments on such things as growing plants, food supplies and the state of the physical body in microgravity. There will also be experiments on sustainability to see if humans can actually live on a foreign planet for an extended period of time without receiving supplies from Earth.

Figure 13- Rendition of a space transport

There are also some commercial companies that are looking into using the lunar surface as a tourism site. Many companies have done research into seeing whether people would actually spend money on a trip into space. Surprising, in a survey of 1,500 Americans, 42% of them said they would be interested in flying into space on a cruise vessel. When asked how much they would be willing spend, the average was $10,800 for the trip. Of course this price is not even close to what the actual cost of a space hotel would be even if it were in Low Earth Orbit, much less

on the Moon. The actual range might be somewhere around 1 million dollars a night. Moon hotels could become very popular amongst the rich people that can afford these kinds of trips and maybe one day the price would be able to drop enough so that the average family could spend a weekend in space. (32)

In order to create a business like a space hotel, the initial setup would be astronomical. There would be people that would have to build the base on the lunar surface as well as a huge infrastructure on Earth to send up the guests as well as supplies to keep them comfortable and well fed. There will have to be a development of a reusable launch vehicle because a vehicle that loses a rocket booster every time it travels to space would be neither economical nor environmentally friendly. However, imagine the possibilities of a hotel on the moon. What will the first Olympic Games on the Moon comprise of?

Conclusions

The combined impact of these technology developments growing out of a new space race will have large implications for Earthly society. The development of a power system for the lunar base, using local resources, will enable Earth to have an ideal fuel source for nuclear Fusion. Having the space agencies and their research partners solve the issues involving the effects of microgravity on the body will very likely result in Earth's inhabitants receiving new more effective and powerful treatments for Osteoporosis and various other ailments associated with aging. Finally, to support all the new activity in space, the space industry on Earth will grow considerably larger in order to meet the sustained demand of a critical trade sector in the economy, the future equivalent of the current oil industry.

Once Helium-3 fusion power is developed on the Earth, it will provide a much needed power source since the world's supply of fossil fuels will be dwindling over the next seventy years. This new power source will be cleaner, safer, and cheaper than all current fuel sources that can provide a sufficient amount of energy to run the current and projected production and transportation sectors of the world economy. If, instituted effectively Helium-3 fusion is a reliable source of power that could supply the Earth with ample energy for a millennium or more.

By solving the effects of microgravity on the human body, treatment methods for several degenerative diseases on Earth will be developed. These disorders include: osteoporosis, muscle atrophy, immune system deficiencies, and

kidney stones. Treatments for these ailments would alleviate the suffering of millions of patients worldwide, and would clearly improve the quality of those patients' lives as they age. It may also lengthen their lives, spinning off a whole new set of social implications.

Due to the increase in space related operations, there will be a large growth in the space industry. This increase in industry will be seen in both unmanned and manned operations. The creation of space platforms that will replace satellites will massively and immediately increase unmanned activity and also give manned space operation their first chance at being economically self supporting. These platforms will lower the cost of telecommunications and other satellite based services. Manned space will then be transformed by the colonization of the moon and the establishment of the Helium-3 trade. These new areas will cause a large economic growth in space related industry, which will create many jobs for people on Earth as the space ports on Earth become as important as seaports in the nineteenth century or airports in the twentieth. These structural changes in the economy, as a new era of exploration and discovery begins, goes along with a large increase in revenue for the multinational aerospace companies.

Future Work

Possible follow-up projects to this one could look at other areas that will be affected by lunar colonization such as the political aspects of claiming territory or the details of the economic changes likely to occur on the Earth. In addition to going into further detail of each of the main areas discussed in the project, other areas to follow up on would be looking into the effects of the possibility of technological breakthroughs, as well as studying the implications of these technologies 20 to 30 years after the period covered by our study. During this period the population on the Moon should go from fifty to five hundred people and the first Mars base will be established at the scale of one of our moon bases, about fifty people. Interestingly, its power plant and fuel supply will probably come from the Moon rather than Earth. What else would be coming from the moon? What will it take to establish agriculture on the Moon and Mars, and produce a self sustaining community? What are the Science fiction depictions of what these first bases will be like, as Asimov, Clark, and Heinlein saw it? Over the next few years the outlines of the future will start to be sketched out and future WPI student will have a chance to see how wide of the mark we were.

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