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The Eighth Continent: A Vision for Exploration of the Moon and Beyond

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Four decades have passed since man first set foot on the Moon. The ensuing euphoria filled us with anticipation and expectation that we would soon visit Mars, but this lofty aspiration quickly faded. Should we return to the Moon? Should we visit some other solar system destination, like Mars or an asteroid? Or should we simply not bother? Debate grows over the justification for a return to the Moon. This paper explores the benefits of pursuing future manned lunar missions for the good of all humanity and to further establish the legacy of the human race as a spacefaring species.

I. Introduction

A decade of national perseverence, courage, and imagination culminated in man walking on the Moon on July 21, 1969. On December 14, 1972, just over three years later, the lunar module ascent stage of Apollo 17 lifted Eugene Cernan and Harrison Schmitt off the lunar surface — marking the last time humans would set foot on the Moon or any other celestial body. At the end of his third and last EVA on the surface, Cernan prophesized:[1]

> *...as I take man's last step from the surface, back home for some time to come — but we believe not too long into the future — I'd like to just (say) what I believe history will record. That America's challenge of today has forged man's destiny of tomorrow. And, as we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17.*

Since then, human space flight has been confined to Soyuz and Space Shuttle expeditions and space station stays in low-Earth orbits[a]. The current U.S. operating space policy was set out in President George W. Bush's Vision for Space Exploration in 2004, prescribing a path "starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations."[2] In response, NASA initiated work on the Constellation program which comprises the Orion Crew Vehicle, Ares Launch Vehicles, and Altair Lunar Lander aimed at returning humans to the Moon.[3] Simultaneously, NASA declared the Space Shuttle program would end in 2010, with Constellation soon after taking its place as a means of launching humans into orbit.[4] Constellation program delays due to technical risks and budget shortcomings,[5] combined with the announcement of the impending de-orbit of the International Space Station,[6] have painted a dismal picture of human space flight prospects in the coming decades.

Since the launch of Sputnik in 1957, a cohesive vision for the future of manned space exploration has been sought on the national and international stages. Countless reports, committees, statements, commissions, symposia, policies, agendas, directives, and conferences regarding space policy and direction have been issued and attended by the government, private industry, and the public. Amidst the current uncertainty of future space flight and the flood of fragments of opinions and ideas, we, the authors, decided to compile a set of explanations answering the single question: Why the Moon? A survey of published works and articles are brought together with new perspectives in the hopes of informing and galvanizing the American public to persuade our government to go forward with what we believe is only the beginning of a flourishing future of manned space exploration.

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[a] Past and current space stations include Skylab, Salyut, Mir, and the International Space Station.

The text is organized into six broad areas, each demonstrating the benefits of manned lunar exploration:

- *Lunar Stepping Stone* focuses on the benefits of learning how to colonize an extraterrestrial body taking advantage of the proximity of our nearest neighbor, the Moon. With such a lunar training ground, we will have the opportunity to develop necessary technologies and harvest lunar resources for future exploration.
- *Pure Science* discusses how returning to the Moon will benefit scientific research such as astronomy, theoretical physics, geology, human physiology and medicine, and Earth sciences through a human presence on a permanently "manned" satellite.
- *Political Concerns* includes matters of defense and international law, and focuses on the potential for unprecedented avenues of international cooperation and collaboration.
- *Saving the Species* addresses several dramatic reasons for near-term lunar exploration and long-term colonization. Even if severe climate change, future asteroid impacts, or global pandemics do not necessitate a mass exodus from Earth, lunar exploits can still teach us how to better utilize Earth's resources through "closed-loop" habitats. Other radical ideas include the outsourcing of harmful processes or learning how to live off-planet so that Earth may be saved as a "nature preserve."
- *Commercialization* addresses creative ideas, both new and old, applied to tourism, real estate, and the commercial use of lunar resources and emerging technologies. The benefits of utilizing the Moon as a product development laboratory and multi-faceted manufacturing venue are also addressed.
- Perhaps the most fundamental reason to return to the Moon and beyond is our *Innate Sense of Exploration and Discovery.* The history of man is based on the continuous migration, colonization, and expansion of human life to the farthest reaches of the globe, from the deserts of equatorial Africa to the yurts of northern Siberia. The Moon is next.

We embark on this journey of explanation with the hope that our vision for exploration of the eighth great continent — that we call Moon — inspires others to take up the cause and propel our species to a brighter and reinvigorated era of reaching for the stars.

II. Stepping Stone to Space Exploration Beyond the Moon

Apollo 17 astronaut Jack Schmitt, the only scientist to walk on the Moon, stated: "It's great that people are interested in Mars." He then cautioned: "But I don't think we'll go there until we go back to the Moon and develop a technology base for living and working and transporting ourselves through space."[7]

One of the most persuasive reasons to return to the Moon is to learn how to explore and colonize extraterrestrial bodies. The total time spent on the lunar surface during the Apollo program was just under 300 hours, and we have no experience at all placing a human being on any other celestial body. Apollo represents the Lewis and Clark expedition equivalent of exploring extraterrestrial bodies: we may have reached far distances, but we have not learned how to live and flourish there. The lunar environment offers a convenient and valuable proving ground with realistic alien conditions so that we may later tackle more ambitious endeavors beyond the Moon. There are important advantages to testing equipment and processes in a "lunar laboratory" where transit time is on the order of days instead of months, and Earth communication times are on the order of seconds rather than minutes.

At any given time, with the proper preparations, we can resupply the Moon in less than three days from the surface of the Earth. This is in clear distinction to "practicing" first on Mars or a Near Earth Asteroid, which would take several months or longer to resupply in the case of an emergency or design flaw.[b] This ability to quickly rescue or resupply is especially important in light of the risk aversion of modern space agencies, with any loss of human life resulting in extended and expensive delays in programs as seen with the Shuttle accidents.

In order to successfully explore space beyond the Moon, it is prudent to first establish and meet lesser goals along the way. Each subsequent goal would be more ambitious than the previous. Such "staged" exploration would be undertaken to incrementally test products and processes, and to discover efficient ways

[b]At its closest approach, Mars is about 150 times farther from the Earth than is the Moon.

to manufacture such products and invent such processes on location. The Apollo program, for example, was the apex of a series of increasingly ambitious programs — Project Mercury followed by Gemini and Apollo — aimed first at placing a man in space, then placing a man in orbit about the Earth, then finally placing a man on the Moon. How convenient it is that we have a nearby Moon to use as an intermediate goal, a less ambitious goal than, say, to bypass the Moon and go to Mars directly.

This staging process would of course first begin on Earth. An Earth-based proving ground is expeditious to developing certain processes, but with a stronger gravity, atmosphere, and more moderate temperature variations, it is not perfectly conducive to testing in a completely representative space environment. The Moon offers the first true alien venue to demonstrate what would be encountered elsewhere in the solar system. On the Moon, we should acquire skills to survive and thrive away from the Earth, before becoming more ambitious. Until we can ford the "river" and learn to live on the other side, we have little business crossing the "ocean."

The development of harvesting in situ resources such as oxygen, water, and energy is a crucial first step. We must also build structures for shelter from radiation, temperature extremes, and the lack of an atmosphere. We must understand how humans react to and interact with the space environment, physiologically (e.g., low-gravity and radiation) as well as psychologically. The need for the development of a lunar staging infrastructure is also seen to be necessary for further exploration. For this, a Moon port is required for receiving and sending payloads from and to the Earth and other celestial destinations, where perhaps a launch system such as a magnetic rail mass accelerator might be feasible. Certainly with plentiful solar energy, no atmosphere to produce drag, and paltry gravity, the engineering demands of the launch and capture mechanisms would be relaxed as compared to that required on Earth. The development of deep space capabilities such as advanced communications and propulsion is also required.

A. Develop *In Situ Resource Utilization*

A recent TIME Magazine article stated: "Another good reason to go [to the Moon first] is the one disdained by straight-to-Mars boosters: learning how to live off the land [and] manufacturing some of what we need from soil..."[8] Self-sufficient transport of all necessary items from Earth, as was done on the Apollo program, is simply prohibitively expensive and is not conducive to "thinking outside of the box" as is typical in explorations. Being self-sufficient is akin to being on a vacation — you pack what you need for a few days and return home once these items are expended. For extended stays, it is far more efficient to develop means of extracting, distilling, and utilizing the resources that are naturally found at the extraterrestrial destination. Due to the extremely high cost of launching and shipping building materials from the Earth to the Moon, utilizing local resources will be key to long-term development of permanent bases in space.

Additionally, because the surface of the Moon is higher up in the gravitational well than is the surface of the Earth, it is far less costly to deliver such materials from the Moon to other destinations in the solar system. Thus development of a lunar base would allow not only practice in surviving off the land for future missions to Mars and beyond, but lunar resources, once harvested and processed, could be sent on to bases or colonies further in the solar system.

As shown in Fig. 1, lunar regolith — Moon dust — is surprisingly rich in chemical elements that could be useful in supporting a lunar settlement as well as exploration beyond the Moon. Table 1 lists some possible uses of these elements.

1. Oxygen

Oxygen is most critically needed in the form of O_2 for humans to breath, but it also is useful for constituting water and in oxidation processes such as propellant. Oxygen is arguably the most critical element to life as we know it. If elements are removed from our environment, lack of oxygen would be the first to kill us. We tend to think that since the Moon lacks air and is surrounded by near-vacuum, there is no oxygen there, but nothing could be further from the truth. As shown in Fig. 1, lunar regolith in fact consists of about 40% oxygen by weight. The overwhelming majority of material found on the Moon's surface contains oxygen. These include oxides of both common and rare metals discussed below. While this abundant oxygen is chemically bound, opportunities for solar power and eventually nuclear fusion, as discussed in Section B, should provide ample energy for extracting the element.[10]

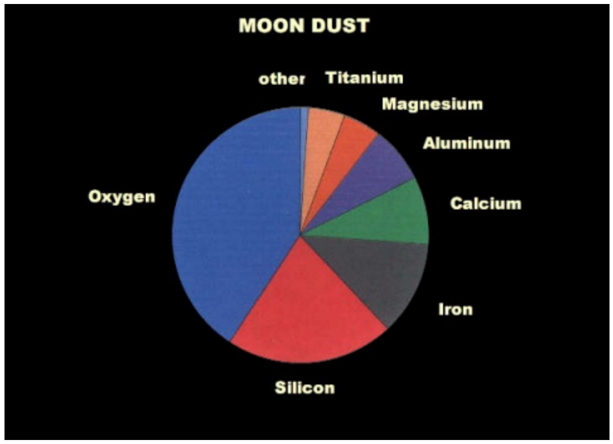


Figure 1: Chemical composition of lunar regolith. Credit: L1 Space Nexus[9]

Table 1: Possible use of elements found naturally on the Moon

Element	Used for
oxygen	breathing, water, oxidation processes
silicon	solar panels
iron	vehicles, structure reinforcement
titanium	steel alternative
aluminum	vehicles, alloys
magnesium	alloys
chromium	alloys, manufacturing processes
potassium	fertilizer, medicines
nitrogen	fertilizer
carbon	chemical products, manufacturing processes
hydrogen	chemical products, water
helium-3	fusion energy

2. Water

Water is of course needed for drinking, agriculture, and manufacturing. It is not only necessary for human survival, as well as food preparation and growth of plants via hydroponics, but it is an important fluid for commercial chemical processing. It is thus a crucial resource to have available, however it is nearly absent on the Moon. Two possibilities are:

- Should water be transported from the Earth to the Moon? It would be expensive to transport. An estimate by NASA places the cost at $2,000–20,000 per kg.[11] Even if water were decomposed into its constituent elements or recombined into some more conveniently transported compound, the transport cost per kilogram of water would be the same.
- Should we discover a way to extract and purify what little water there may be on the Moon? Water would have to be present in sufficient quantities, whether it exists in liquid or ice form or encapsulated in other materials in elemental or compound form. Either way, water would need to be harvested, extracted, reconstituted and purified from its in situ form. Once used, recycling of this commodity would be important.

It remains uncertain how much water exists at or below the lunar surface. There is the possibility that ample water is sequestered in the permanently shadowed areas of the polar craters or underground. Paul

Spudis, a scientist on the Clementine mission study, believes the polar ice mass may be "the most valuable piece of real estate in the solar system."[11] The upcoming mission LCROSS (Lunar CRater Observation and Sensing Satellite) may help give an indication of the abundance of this important resource.

Another possibility, derived from theoretical arguments, is that constant bombardment of the lunar surface by hydrogen ions (alpha particles) from the solar wind could provide hydrogen as a byproduct by mining the compounds in the lunar regolith that have been created by the bombardment process.[12] But the surface of the Moon so far has revealed only paltry signs of hydrogen.

Another recently-discovered possibility is the extraction of water molecules from volcanic glasses that litter the surface of the Moon. Figure 2 pictures volcanic glasses containing water molecules brought back from the Moon by Apollo 15. The volcanic glasses are thought to be byproducts of lunar "fire fountains" which ejected magma over three billion years ago.[13] It is not clear how much water may exist in this form, and, if present in sufficient quantities, how sufficient quantities would be efficiently extracted. At any quantity, water will clearly be a valuable and scarce resource on the Moon.

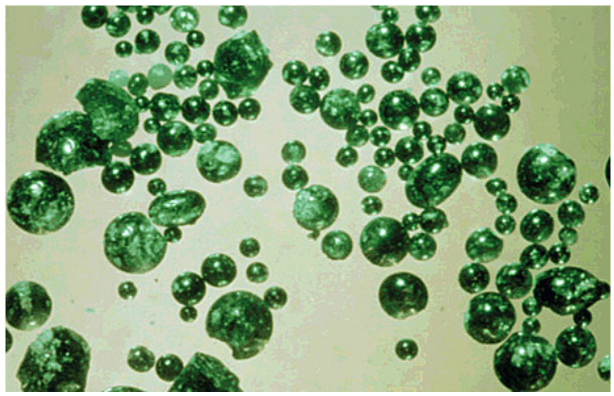


Figure 2: Thirty-seven years after Apollo 15 returned Moon matter to the Earth, geologists have found a means of extracting water molecules from glass particles found in the Moon matter. Credit: NASA[13]

3. Food

Long-term human habitation of the Moon would require either regular deliveries of food or the development of lunar farming methods. We focus here on the latter. Growing food of sufficient variety, quality, and quantities outside the Earth's biosphere will be significantly challenging. Such challenges include cultivation in low gravity and in the presence of unfiltered sunlight and radiation, protection from the natural vacuum, the availability of sufficient amounts of water and fertilizer, and the adaptability of plants to grow in a lunar-based medium. What we learn about growing food on the Moon will have direct applicability to growing on other planets.

Figure 3 depicts a recent proposal to place a miniature greenhouse on the Moon to distinguish if hardy vegetables or flowers can be grown. At issue are how plant growth would react to one-sixth gravity, cosmic rays, the light of the sun unfiltered by an atmosphere, and temperature swings.

In another study, it is hypothesized that the first generation of plants would be the source of protosoil of sufficient fertility for future generations of plants suitable for human consumption.[15] The study further deemed: "The residues of the first-generation plants could be composted and transformed by microorganisms into a soil-like substrate within a loop of regenerative life support system. The lunar regolith may be used as a substrate for plant growth at the very beginning of a mission to reduce its cost."

4. Helium-3

The ready availability of helium-3 on the lunar surface has stimulated great interest in returning to the Moon. An isotope rare on Earth, helium-3 holds promise of being an ideal fuel for fusion reactors.[16] The use of helium-3 as a fusion fuel is further discussed in Section II.B.

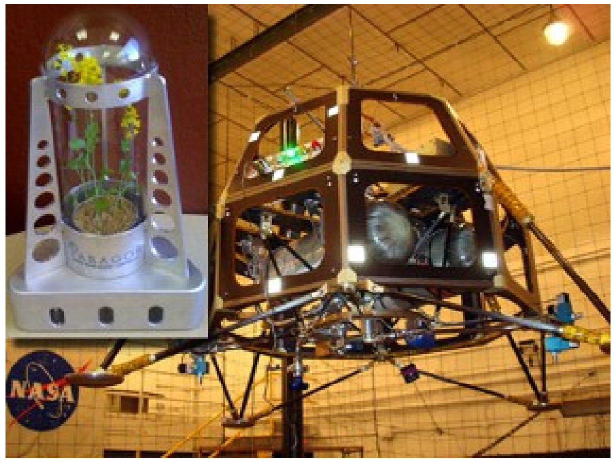


Figure 3: Odyssey Moon's lunar lander with Paragon's lunar greenhouse nicknamed "Lunar Oasis." Plants would grow in a gelatin-like nutrient-rich mixture called agar, with the right amount of carbon dioxide supplied to them and the by-product oxygen syphoned away and perhaps recycled elsewhere. Credit: Odyssey Moon & Paragon/NASA Ames Research Center[14]

5. Silicon

Next to oxygen, silicon is the most abundant element found on the lunar surface, comprising about 20% of lunar regolith as shown in Fig. 1. Again, it is bound up as an oxide, but processing to liberate both the pure silicon and pure oxygen will produce two useful resources. According to some experts, the bountiful silicon on the Moon can be extracted and turned into solar cells.[8] With the availability of plentiful sunlight, silicon-based solar cells will supply much-needed power.[17]

6. Glass and Related Fiber

Perhaps sooner than production of solar cells, silicon dioxide will be used in the production of building materials. Glass will be a useful building material to allow light into structures such as greenhouses. Glass will also be important to protect solar cells from abrasive lunar dust and as an internal building material. Windows inside of lunar structures are an important human factor to help us feel at home. Glass fibers can also be manufactured as a building material for lunar structures and future machinery built on the Moon. Glass used for external structures will have to be quite thick to withstand both radiation extremes and pressure differences inside of buildings. This again favors producing large quantities of glass locally as opposed to shipping bulk glass on expensive launch vehicles.

7. Building Materials

"Lunarcrete," also known as "mooncrete," was first proposed by Larry A. Beyer of the University of Pittsburgh in 1985 as an aggregate building material that would significantly reduce the cost of building structures on the Moon.[18] To protect humans from the elements (e.g., radiation, vacuum, thermal extremes), structures and barriers can be constructed using lunarcrete, consisting mostly of silicon extracted from lunar regolith.[19] One study indicates that 2 meter thick regolith-based walls and ceilings would provide adequate shielding from both cosmic radiation and solar proton events.[20] As pointed out in the last paragraph, another possibility for building materials is the use of glass and fiber-glass from regolith.

8. Metals and Minerals

In addition to more common products like glass and concrete, the Moon has a significant number of metals for structures and rare metals for other industrial production purposes. These metals include iron, aluminum, titanium, magnesium, manganese, and other elements used in space age materials. We know these resources are present on the surface of the Moon in reasonably abundant quantities from the legacy of the material brought back from all of the Apollo landing sites. There is also the possibility that these and other materials, different than those present on the surface of the Moon, exist at depth and could be mined.

There are other discoveries yet to be made regarding available natural resources on the Moon. As will be discussed in more detail in Section III.F, the theory is that the Moon was formed from a piece of the primordial Earth as the result of a collision billions of years ago. Along with countless impacts from space debris, the Moon is very likely to contain most of the raw mineral materials found on Earth, except volatiles which have evaporated off of the lunar surface. LCROSS is a NASA mission which is currently on its way to the Moon as this paper is being written. The mission will impact one of the Moon's polar craters and fly sensing equipment through the resulting plume. Since the bottom of many polar craters are constantly in darkness and cold, there is conjecture that they may contain hidden, frozen water-ice. The spectrometry that will be performed on the impact dust plume will help expand our knowledge of the relative abundances of other materials available as resources on the Moon.[21]

B. Power Generation

Once there is commercial activity on the Moon, generation of power will be necessary. There are several potential power sources which might be expoited on the Moon, some of which could perhaps be beamed back to Earth. Possibilities for the production of energy on the Moon using current technologies include solar, chemical, nuclear, geothermal and terminator-static.

1. Solar Electric

Solar energy is the most obvious power supply, and it will probably be the main source at least at first. There is no atmosphere on the Moon, so light from the sun is not attenuated as it is here on Earth, thus allowing greater output power from the direct sunlight. Potential downsides include electrostatic dust coating the cells, 14-day lunar cycle, and higher radio-active wear on equipment. Long-cycle batteries or alternative power supplies could be used to bridge the 14-day nights, which are not experienced at some places near the lunar pole where there is full time solar exposure to vertically erected solar panels..

2. Helium-3 for Nuclear Fusion

Due to the Moon's billions of years of radiation bombardment without an atmosphere to block the incoming particles, the Moon appears to be relatively rich in radioactive isotopes that are more rare on Earth. For example, samples have shown that the abundance of heavy helium isotopes is much greater on the Moon than Earth.[22] The Fusion Technology Institute at the University of Wisconsin first identified the existence of the lunar helium-3 fusion fuel in 1986, and they maintain an online gallery of related news articles.[22]

The commercially interesting thing about helium-3 is that it is a leading candidate to fuel future nuclear fusion power plants. If and when nuclear fusion becomes a viable technology here on Earth, this abundance, along with the vast amounts of energy that can be released from a relatively small mass of reacting helium-3, may make it commercially profitable to mine helium from the Moon and return it to Earth as a power supply. Likewise, fusion plants could later produce power on the Moon itself or on vehicles utilizing the Moon as a stepping stone for further exploration and activity. Thus, the Moon may contain a key power resource for our future on Earth and in space.[23–25]

3. Uranium for Nuclear Fission

Along with heavy helium, returned samples have shown evidence of uranium in the lunar regolith. As the regolith is processed for more common elements such as oxygen and silicon, uranium could be produced as a by-product. Thus the Moon may also produce fuel for more traditional nuclear fission power.

4. Terminator Potential Difference

The Moon has little or no atmosphere to discharge or "ground" static electrical buildup in the regolith. This is one explanation for why the lunar dust was so statically "sticky" during the Apollo missions. On a larger scale, portions of the Moon bathed in sunlight gather a net positive charge from the effects of solar radiation and particle flux. On the other hand, portions of the Moon exposed to the darkness of deep space gather a net negative charge due to a net flux of radiation with the opposite ionizing effect. It has been estimated that there is an electical potential difference between the light and dark side of the Moon which may have a magnitude of up to thousands of volts. Since there is no atmosphere to carry the charges to allow this potential difference to "drain" or balance, nor to spread and scatter light and radiation in a dawn or dusk, there is a relatively distinct moving line between the lunar day and night — this is called the lunar day-night terminator.

Astronauts on the Moon reported seeing a glowing effect across the lunar horizon while looking towards the terminator. It is surmised that this was actually charged lunar dust being drawn across the voltage difference at the terminator. If so, the bad news is that a roving sunrise and sunset static dust storm could be very hard on equipment. The potentially good news is that this large potential difference across a short terminator could theoretically be "drained" by embedded conductors, both reducing the dust effects and potentially generating and storing enormous amounts of power. While the static difference is probably greatest at the lunar equator where the most direct sunlight strikes, there are likely places at the lunar poles where the distance across the terminator is relatively short, and may be amenable to a permanent power station. Of course, the details of this static-terminator effect will have to be further studied to see if such a system would be feasible for power generation.

5. Heat Pump

Due to the roughly 28-day lunar cycle, the surface of the Moon undergoes an average 260°C temperature change, yet there is little variation in the temperature of the lunar regolith just a few centimeters below the surface.[26,27] The temperature at a depth of 1 meter is in fact nearly a constant −35°C. Such a large spatial temperature differential over a short distance could allow an efficient heat pump to produce a significant amount of energy.

Similar to the polar static electric terminator, there are also extreme differences in temperature between areas of the Moon in sunlight versus darkness. An interesting example of this could be a permanently dark crater and a neighboring permanently sunlit hill at one of the poles. Thermo-couple or thermopile technology could convert this temperature difference into electical power for supplying commercial and other ventures on the Moon. Further research and development of the idea would be necessary to determine feasibility.

C. Lunar Training Ground

How to colonize extraterrestrial bodies is for the most part completely unknown. Utilizing the Moon as a "training ground" before embarking on ventures orders of magnitude more complex is prudent engineering that will add a factor of safety to human activities in space. A lunar training ground would allow the development of a colony infrastructure, complete with buildings, cultivation equipment and processes, manufacturing capabilities, ground transportation, and deep space capabilities such as communications, navigation and propulsion. Some notable areas are discussed here.

1. Human Factors

Human beings must learn to cope in an alien environment for long periods of time, far away from their Earth homes. Physiologically, we must learn to live with or protect our biological systems against abrasive dust in low moisture environments that may exist on Mars and some near-Earth objects. We also need to understand and mitigate physiological risks associated with the radiation, thermal conditions and low gravity of harsh planetary environments. The great distances and time spans that space travelers will be away from their homes, loved ones, and friends would take a psychological toll that would also need to be addressed. Other psychological issues will include new forms of stress related to the alien environment and small-group social behaviors (e.g., cliques) that must be understood and reckoned with.

2. Telerobotics

Another area of technology that will be driven by lunar development will be in the area of telerobotics. Due to the radiation exposure and dangers of solar storms, it will make a great deal of sense to build and operate robots to do the "manual labor" on the lunar surface, preserving precious human excursion hours for tasks more suited to our adaptable intellect, such as science and R&D.[28] The mundane tasks will also drive the development of semi-autonomous software to improve function and efficiency of the machine laborers. In addition, robots needed for tasks on the lunar surface will be adaptable for use for tasks back on Earth for tasks such as for mining, agriculture, and hazardous material cleanup.[29] This is a rather open and important area; robotics used as an extension of daily human reach to perform tasks that are otherwise hazardous to humans.

3. Perfect Contamination Mitigation Methods

An attendant risk of going directly to Mars is that we could unknowingly kill any life that might be present. During the Apollo program, we knew little concerning the risks in delivering Earth-based microbes or bringing back alien microbes from the Moon. Granted the lunar astronauts were quarantined when they returned to the Earth, but not much was done to address the possible infestation of Earth-based microbes on the lunar surface. It was simply reasoned that they would not survive the radiation, temperature variation, and vacuum; even if they did, they would find no water or food to nourish them. If and when we go to Mars, we cannot think like this. Mars is perhaps less alien than the Moon, so it would seem that there is a better chance of microbes surviving there. We simply need to understand how to mitigate this risk and first test mitigation methods in a "lunar laboratory" setting.

This section concludes by summarizing our agreement with Jack Schmitt's belief that we need to return to the Moon before "living and working and transporting ourselves through space."[7] First, the Moon is by far the nearest and most convenient extraterrestrial body to develop and test products, processes, and systems for space exploration. That is, the Moon is a natural "training ground" where we can learn how to colonize new extraterrestrial territory. Second, the Moon's surface provides a natural "base camp," representing a component of a staging infrastructure for further exploration and commercialization of space. Third, the Moon contains resources at or near its surface which we can exploit. These resources not only allow less baggage to be brought from the Earth to set up such a Moon base, but also can be used to fuel the construction of transportation and support systems that will allow us to travel to other destinations. Fourth, it has been decades since we set foot on an extraterrestrial body, and the scientists and engineers who led the Apollo effort 40 years ago are soon to retire or have so already. Lunar missions would allow us to regain the expertise necessary to operate manned missions beyond LEO with modern standards and capabilities in mind.[30]

III. Pure Science

Many fields of science stand to benefit from scientific experimentation in space and, in particular, on the Moon. Advancement in fields such as astronomy, astrophysics, astrobiology and theoretical physics as well as human physiology and medicine, physical sciences, and planetary and Earth sciences will benefit through a human presence on a permanently "manned" satellite.

To place our current notion of scientific knowledge into perspective, in 1935 a prominent British astronomer estimated the age of the universe at 10,000 billion years.[31] At that time, it was ludicrous that such an estimate could be made at all or even that the universe was thought to have a finite age. Modern observations and current theories estimate the actual age to be only $1/700^{th}$ of the estimate made 75 years ago. This begs the question, how will we view the substance and correctness of today's scientific theories 75 years hence? Will they appear as naive then as 1935 theories do now? The point is that today's scientific theories will be revised and revised again, but more importantly, completely unexpected discoveries will be made leading to radically new scientific theories. Experimentation on the Moon would perhaps accelerate such discovery, since it offers a unique laboratory very much in contrast with that which we find on planet Earth.

A. Astronomy

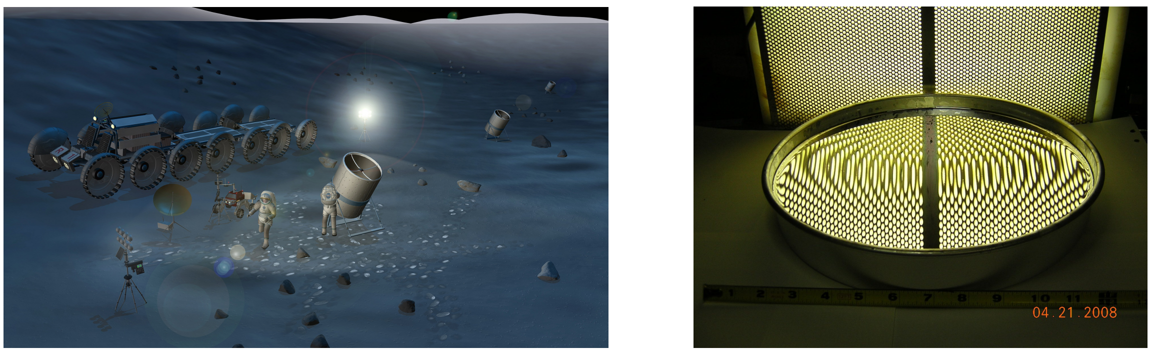
1. Optical telescopes

The Moon would be a wonderful base for astronomical observations. There is no atmosphere to interfere with the path of incoming light, the sky is dark and thermally cold, and the Moon is seismically dead which would enable the use of more sensitive instruments. In addition, the fourteen Earth-days of night allow longer continuous observations which can be useful when observing the dynamic behavior of the heavens.

Furthermore, the lunar surface is solid enough to support very large structures. Such large structures would not be disturbed by the wind as they would on Earth and potentially could be much larger due to the lesser force of gravity. Perhaps most importantly, the far side of the Moon is shielded from radio frequency energy sources originating from Earth, allowing virtually noise-free observations over a broad range of radio frequencies.[8]

Astronomers disagree on whether a Hubble-like orbiting space telescope or a lunar-based telescope is better for peering into the far reaches of the universe. The lunar telescope may be more difficult to transport and assemble on the Moon, but placement of such a telescope on the far side of the Moon would have the very significant advantage of being shielded from radio and optical interference from the Earth.[32]

NASA is contemplating placing arrays of matched telescopes in orbit around the Earth, with the advantage that the combined light would result in pictures much sharper than from the single-element Hubble Space Telescope. The search for distant Earth-like planets would benefit greatly from such a configuration. On the Moon, the telescopes can be made larger and they can be separated at longer distances since their formation is fixed to the surface of the Moon rather than flying in a formation which must be precisely controlled.[8] Such a lunar-based telescope array system is illustrated in Fig. 4a.



(a) (b)

Figure 4: a) Artist's concept of astronauts erecting an array of telescopes on the Moon. Credit: NASA,[33] b) A 12-inch mirror made from simulated moondust. Credit: Peter Chen/NASA/GSFC[34]

To alleviate the obstacle of transporting large amounts of material to the Moon, NASA is contemplating the fabrication of large telescopes up to 50 meters in diameter with materials which mostly originate from the Moon.[34] Spincasting a special vacuum-stable cryogenic polymer with native regolith solidifies into a parabolic surface which then can be polished into a suitable mirror for a telescope. The unpolished material has properties similar to hardened cement, allowing the "lunar cement" to also be used as building blocks for other structures such as human shelter. The vacuum conditions on the Moon would be ideal for the manufacturing process of such mirror. Building a mirror of the same size as the Hubble Space Telescope would require transporting 60 kg of epoxy, 1.3 kg of carbon nanotubes, and a trivial amount of aluminum to the Moon. In situ materials would include 600 kg of regolith, making up 90% or more of the mirror.[32] Figure 4b illustrates a small mirror manufactured on Earth using simulated moondust.

Perhaps the first large moondust telescope can be formed within an impact crater that is reasonably shaped like a paraboloid. There are, however, challenges to implementing this concept. Two such challenges are a) transporting the spinning table used to manufacture the material to the Moon, and b) preventing lunar dust from contaminating the manufacturing process.

The International Lunar Observatory Association (ILOA) is focusing on private Moon missions with goals to place modestly-sized telescopes on the Moon within the next decade. "The primary goal of the ILO mission is to expand human understanding of the cosmos through observation from our Moon."[35]

2. *Radio telescopes and interferometers*

Much of today's cosmological inferences are made with large radio telescopes that peer into the "Dark Ages" of the universe. Events such as the formation of galaxies, black holes, and the very first exotic stars can be viewed with radio telescopes tuned to the hyperfine transition of neutral hydrogen (21 cm rest wavelength).

Physical properties of the universe such as curvature and the state of the intergalactic medium can also be explored.[36]

The Lunar Radio Array illustrated in Fig. 5 is a proposed radio interferometer consisting of a large number of science antennas. "Hydrogen is the dominant component of the intergalactic medium (IGM), and LRA observations potentially will provide information prior to the formation of the first stars and unique information about the state of the IGM and large-scale structures after the first stars form."[37] The far side of the Moon is deemed to be very attractive for placement of the LRA because Earth observations are masked by Earth's ionosphere and anywhere else near the Earth-Moon system is subject to man-made radio interference.[37]

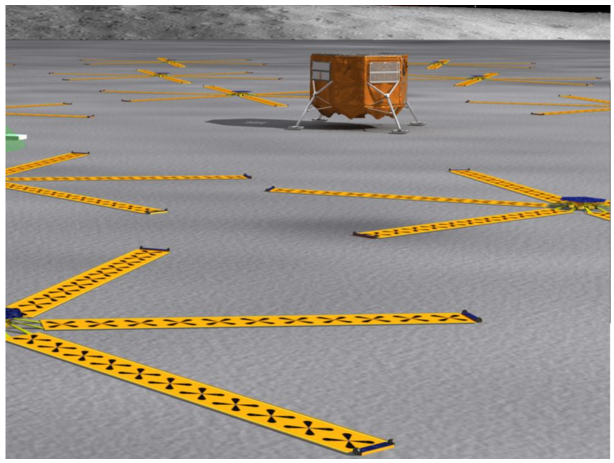


Figure 5: Artist's conception of the Lunar Radio Array placed on the far-side of the Moon. Credit: Jet Propulsion Laboratory[37]

Theoretically, an Earth-Moon scale interferometer would provide spectacular resolution as compared to an Earth- or lunar-based interferometer. Earth-based interferometric systems can now observe quasars and other distant objects in the universe. Two key requirements that govern the sensitivity of interferometric measurements are baseline distance and stability of that distance over time. The longer the baseline, the better the measurement is in terms of resolution. An Earth-based interferometer can have a baseline no larger than the diameter of the Earth, with baselines of existing systems running between 4,000-8,000 km. The Earth-Moon distance of about 400,000 km would allow an interferometer with a baseline two orders of magnitude larger than that of an Earth-bound interferometer.

B. Theoretical Physics

The spartan environment of the Moon and its remoteness from Earth offer the opportunity of a venue to collect extremely sensitive measurements from which inferences can be made in theoretical physics. Forty years ago, for example, Apollo 11 placed a simple laser corner reflector on the Moon's surface as illustrated in Fig. 6. The Lunar Laser Ranging Experiment is unique in that it has been continuously operated since the Apollo 11 mission. From this ongoing experiment, it has been learned that the Moon has a fluid core, is receding away from the Earth at 3.8 cm/year, and a facet of Einstein's theory of relativity was verified.[38]

Gravitational wave and high energy particle detection is possibly more feasible on the Moon. Further tests of Einstein's principles such as gravitational well and frame-dragging could also benefit from experimentation in the lunar environment.

C. Physical Sciences

It is significant that the surface of the Moon is not prone to decay or change as it is on the Earth, where erosion due to wind and rain completely mask prehistoric processes. Although there is no oceanography or atmospheric science to study on the Moon, there is geology, craterology, and chemistry whose history has been preserved through the eons of time. Unraveling the secrets within such a "time capsule" would

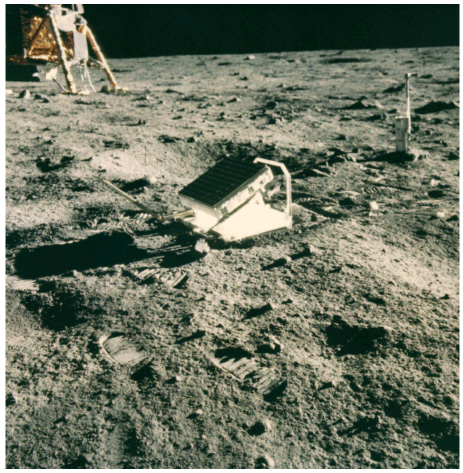


Figure 6: Deployed on the Moon by Apollo 11, 14, and 15, Laser Ranging Retroreflectors were used to precisely measure orbital parameters and to help verify Einstein's theory of relativity. Credit: NASA

have enormous impact on our understanding of the origin and physics of the Earth. Entry into entirely new fields of physical science would be offered by investigating the chemical makeup of regolith, the origin and consistency of lunar caves, and solid physics of the Moon's substrata.

D. Astrobiology

A recent white paper by the NASA Astrobiology Institute offers the following benefit of in situ scientific study of the Moon:[39]

> *The Moon preserves unique information about changes in the habitability of the Earth-Moon system. This record has been obscured on the Earth by billions of years of rain, wind, erosion, volcanic eruptions, mountain building, and plate tectonics. In contrast, much (most?) of the lunar surface still contains information that reflects events at the time of life's origin and subsequent evolution on Earth. Therefore, lunar research can address critical astrobiology science questions. In particular, the lunar record allows us to focus on two specific issues in the early solar system: the history of impacts and the history of exposure to radiation. The Moon, as Earth's closest neighbor, is probably the only body in the solar system where we can address these issues quantitatively.*

By understanding the bombardment rate of objects onto the Moon back to life-formative times, one can better understand Earth's habitability throughout the existence of life. From the time of life's origin through times of impact-driven mass extinctions, evolutionary effects known to have occurred on Earth might be better explained through such lunar-based observations. Recorded in the lunar regolith are events triggered by solar activity, cosmic rays, nearby supernovae, and gamma ray bursts; they can help shed light on sudden evolutionary effects observed on Earth.

E. Human Science

At the beginning of the space age, important questions arose about how human beings would react when they traveled away from Earth. Would a human being survive the acceleration of a rocket impulse that propels him into space? How would he be protected from the vacuum and radiation of space? What can be done to control temperature extremes? What are the long-term effects of weightlessness on the human body? What are the long-term sociological, physiological and psychiatric effects on the human body and mind? How are medical conditions diagnosed and how is medicine administered in space? Although much has been gleaned about human science in space through manned orbital space flight, little is known about such science when man is on an extraterrestrial body. The Moon offers a unique venue to help answer such questions with regards to biology, biochemistry, medicine, physiology, and psychiatry.

F. Planetary and Earth Science

Clues to the origin of the solar system that may be revealed by examining the geophysics of the Earth have been obscured by such processes as erosion and plate tectonics. Nonetheless, we have discovered a good number of facts relating to the history of the solar system simply by understanding our home planet. In situ geophysical and geodetic investigations have revealed much as to the Earth's origin, dynamic change, future fate, and place in the solar system.

The Moon, on the other hand, preserves originating evidence very well, but it is not within easy reach to perform the necessary close examination to draw accurate and verifiable conclusions. In situ scientific study of the Moon will dramatically increase our knowledge of planetary science. In addition, lunar physics such as volcanism and the deformation of the Moon's crust will benefit. Detailed in situ study of a second body, the Earth being the first, will also help us understand the vast differences we observe between the different bodies in the solar system. Forensic investigation of the Moon will greatly help us unravel the mysteries of how the Earth-Moon system was formed. Going to the Moon is the only clear way to perform such lunar forensics with an adequate degree of certainty.

The theory in vogue today is that the Moon formed when a Mars-sized body collided with Earth during the formative years of the solar system. As shown in Fig. 7, computer models suggest that a glancing blow by this body scattered mass at about the right distance from the Earth to eventually coalesce into the Moon.[8,40] "For the first time, we demonstrated with simulations that a single impact can give you an iron-depleted Moon of the right mass, and the current mass of the Earth, and the current angular momentum of the Earth-Moon system."[40] In situ investigation on the Moon will certainly help validate such theories, or perhaps provide the smoking gun that might dismantle this reasoning.

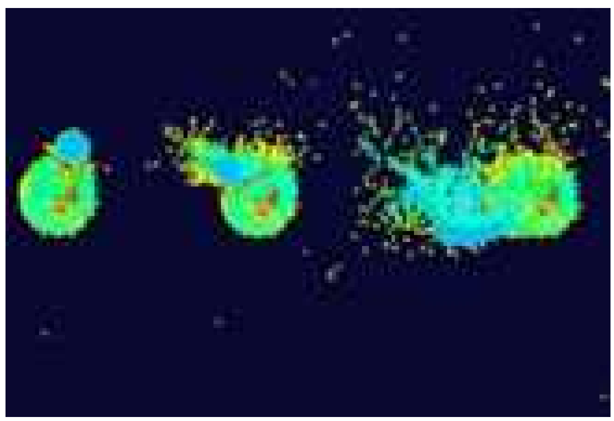


Figure 7: The smaller Mars-size blue object approaches and collides with Earth setting it spinning. Credit: Southwest Research Institute[40]

Through in situ lunar investigation, what is found to apply to the Moon and to the Earth-Moon system will accelerate our thinking about planetary science in general. Ancient interplanetary and planetary collisions are certain to be a key to unlocking the secrets of the solar system, so it would seem a solid understanding of this system closest to home is in order.

In summary, bold advancements in science can be made through a continual presence on the Moon. Many of these advancements can be made robotically, but historically the most spectacular findings have been made when man is present to perceive what is occurring during an experiment, to adjust the apparatus for better sensitivity or for a more perceptive view, and to hypothesize (in situ) a theory to explain what was observed. Such human presence at a lunar science base will inevitably open up new realms of science.

IV. Political Concerns

The launch of Sputnik I in 1957 provoked world-wide shock at this first artificial Earth-orbiter, fear of the Soviets' intentions, and indignation at the militarization of space. From this inception of the Space Race to the current international stage featuring burgeoning Chinese and Indian space programs and fledgling programs in North Korea and Iran amongst others, politics has played a large role in space ventures. This section, divided into purely nationalistic concerns and international considerations, leads a broad view to the political advantages of expanding a human presence in space and, in particular, on the Moon.

A. Winning a New Space Race

The great Space Race of the 1950's and 1960's, besides boosting the level of education in the Unites States and providing myriad technological bursts, gave the nation a vision and clear goal to reach towards. Forty years has passed since man first stepped on the lunar surface and successfully returned to share the experience, science, and sense of achievement with the world. The technology able to sustain a permanent human presence on the Moon, the first step to space colonization, is now on the cusp of existence. With several countries expanding their space programs in leaps and bounds with sights on the Moon and beyond, a space race of a different sort is about to emerge. Can the United States afford to take a step back and curtail human activities beyond our planet?

In the last two years, India, China, and Japan have all carried out successful lunar orbiter missions (Chandrayaan-1, Chang'e 1, and Selene or Kaguya, respectively) exploring the lunar surface features and resources ostensibly as a first step towards the manning of a permanent lunar outpost.[41–43] It is unclear what advantage the first country to return humans to the Moon might gain; resources and land might be up for grabs, defensive military early-warning or launch capabilities might be possible, etc. More importantly, the "winning" country stands to become — or prove that they remain — a leader in space technology and such a success will stand as a symbol of international stature and economic development. A renewal of the space race mentality, with a manned lunar base and space colonization as a new national goal, could once again unite our country and foster national pride and patriotism.

B. Influencing Future Laws

International considerations include preventative politics and global cooperation. With space law currently in its infancy, the prevailing treaties and various agreements will need to be extensively augmented in the coming years, and major players on the space stage may well have influence in shaping laws governing the future of all things space-related. Of significant import are issues relating to the militarization of space, ownership and use of "land" and resources, and protection of the space environment.

The United Nations Committee on the Peaceful Uses of Outer Space created five treaties and agreements between 1967 and 1984 which constitute the majority of the body of space laws in place today. According to the Committee: "the international legal principles in these five treaties provide for non-appropriation of outer space by any one country, arms control, the freedom of exploration, ..., the prevention of harmful interference with space activities and the environment, the notification and registration of ... the exploitation of natural resources in outer space and the settlement of disputes."[44] However, many nations have chosen not to ratify the treaties, meaning that these regulations have not been universally accepted. Imminent lunar and martian exploration by a few countries implies a need for current space laws to be globally ratified and the inception of supplementary treaties or agreements as the need arises. Future amendments or treaties might lean towards favoring those countries at the leading edge in space activities, the effects of which might have unpredictable negative consequences for the prosperity, influence, and safety of those countries who are not.

C. Controlling the Militarization of Space

Militarization of space has remained a hot topic since the announcement of Sputnik's success in 1957. The UN Outer Space Treaty[c] and Moon Agreement[d] (Treaties I and V, respectively) broadly state that nuclear

[c]full name: Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies

[d]full name: Agreement Governing the Activities of States on the Moon and Other Celestial Bodies

weapons and other weapons of mass destruction cannot be stationed in outer space or on any celestial bodies, and that the Moon shall be used exclusively for peaceful purposes.[44] Not only does this appear to allow weapons of "minor" destruction in space, but China, Russia, and the United States have yet to sign or ratify the Moon Agreement of 1984.[45]

Recent activities such as the self-destruction of satellites by China in 2007 and the United States in 2008 have raised concerns that these were in fact tests of anti-satellite weapon technologies and the beginning of a new arms race.[46,47] The United States has not only voiced that their maneuver was necessary and not to be construed as the beginnings of such an arms race, but has also consistently opposed development of any legal restrictions seeking to limit access and use of space.[47–50] The reasons for this are the same as those that warrant a continued American presence in space and on the Moon: securing future success, prosperity, and safety by promoting our national interests. The U.S. National Space Policy of 2006 states that freedom of action in space will "increase knowledge, discovery, economic prosperity, and ... enhance national security" and that, consistent with the principle of the peaceful use of space, "U.S. defense and intelligence-related activities in pursuit of national interests" should be allowed in space.[50–52]

D. Controlling Ownership of Space and Its Resources

Although private ownership of lunar land and space resources has been touted as an important impetus to future space development, this area of the law is fuzzy. The UN Outer Space Treaty (the first of the five UN treaties and agreements of space law) states clearly that "outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[44] Some maintain that this does not define the legal status of private companies or individuals wishing to claim property rights or to develop, extract, or manage celestial resources.[53,54] The Moon Agreement of 1984 (the fifth UN document) clarified this position by stating that "the moon and its natural resources are the common heritage of mankind" and that the lunar suface, subsurface, and resources could not "become the property of any State, international intergovernmental or non-governmental organization, national organization or non-governmental entity or of any natural person."[44] This agreement, however, was not signed or ratified by the major space-faring nations: China, Russia, and the United States.[45,55] With the possibility that either private institutions will one day be recognized as lawful land/resource owners or that future regulations allowing state sovereignty will be put into place, present actions will have huge political, strategic, and commercial implications.[53] Thus, the United States should plan to support a strong manned lunar and space presence and, if deemed beneficial, use this clout as a powerful space-faring nation to promote legal initiatives to better define space and resource ownership.

E. Promoting International Cooperation and Peace

President John F. Kennedy was among those who "hoped that competition among diverse states ... could be channeled into peaceful pursuits — exploring the cosmos as the moral equivalent of war."[56] A venture to the Moon and eventually beyond could become the ultimate ground for collaboration between nations and international peace.

Tenuous lunar partnerships linking technologically-advanced Russia with economically-booming India and China have recently been established.[57,58] Such collaborations, allowing each nation to specialize in different elements of the endeavor and to share in the cost of development, might be the only plausible way to complete such costly and complex missions. The precedent has already been set for international cooperation in space with the Hubble Space Telescope, the Cassini-Huygens mission to Saturn, and the International Space Station (ISS).

Perhaps the most impressive display of international cooperation, the International Space Station (Fig. 8), is a result of collaboration between the United States, Russia, Japan, Canada, Brazil [e], and the ESA[f] — 15 countries all told. This venture to "enhance the scientific, technological, and commercial use of outer space" required the combined resources, expertise, and efforts of these nations around the world.[60] As Umberto Guidoni, a former ESA astronaut, said: "For the first time in history all the major countries in the world are pushing together to reach this goal... building something in space that is really for all humankind."[61]

It is this "internationalism" which reinforces interdependence, allows mutual concerns and interests to multiply, and positively reinforces international political stability and political relations between nations.[60]

[e]Operating through a separate contract with NASA.[59]

[f]Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, and Switzerland.

(a) (b)

Figure 8: a) The insignia of the International Space Station. Credit: Swedish Museum of Natural History,[62] b) The flags of countries collaborating on the International Space Station.

Similar to the politically-neutral, scientifically-based habitation of Antarctica, we propose the Moon to be the ultimate neutral location for international collaboration — the future ground for common interest and understanding — a foundation for peace.

V. Saving the Species

"[There is] one very powerful motive...that may ultimately trigger the expansion of global human civilisation into the extra-planetary realm — survival."[63] This section describes two different scenarios in which returning to the Moon is required for the preservation of humanity. The first addresses circumstances under which space colonization becomes a necessity because humans would be forced off-planet in order to survive. Using the Moon as a stepping stone to larger scale colonization will be discussed in Section II. The second scenario assumes humans remain on Earth and utilize the Moon to maintain a habitable Earth.

A. Uninhabitable Earth

The smartest minds of our time have kept up a continual warning that the human occupation of Earth is limited.

> *In the long run a single-planet species will not survive If we humans want to survive for hundreds of thousands or millions of years, we must ultimately populate other planets... I know that humans will colonize the solar system and one day go beyond.*
> *—Michael Griffin, former NASA Administrator*[64]

> *I don't think the human race will survive...unless we spread into space. There are too many accidents that can befall life on a single planet.*
> *—Stephen Hawking, world-renowned theoretical physicist*[65]

> *If our long-term survival is at stake, we have a basic responsibility to our species to venture to other worlds. Sailors on a becalmed sea, we sense the stirring of a breeze.*
> *—Carl Sagan, eminent scientist and promoter of SETI*[66]

> *The extension of life beyond Earth is the most important thing we can do as a species.*
> *—Elon Musk, founder of SpaceX*[67]

These opinions that the future survival of the human race depends on an ability to move in the direction of human space colonization originate from an understanding of the myriad dangers facing a single-planet species.

1. Dust Loading due to a Near-Earth Object Collision, Volcano, or Nuclear Exchange

"But then Mother Nature suddenly and unexpectedly deals a wild card! Something happens, and happens quickly — a planet-wide event that upsets the ecological equilibrium...."[63] One such cause of human extinction often dramatized by Hollywood is a catastrophic asteroid collision with Earth. Earth's geological and biological history has been shaped by impacts. The most famous instance is the K/T mass dinosaur extinction, believed to have been caused by a 10–15 km diameter near-Earth object (NEO).[68] Figure 9 shows the correlation between impact frequency, energy, and size. Many of the major extinctions in the history of life, including the largest which gave rise to the Permian/Triassic geological period boundary, are now believed to have been caused by impacts of large NEOs.[68] Impacts of this magnitude (>1 km) are considered "civilization-threatening" events and endanger the continuation of our species.[69,70]

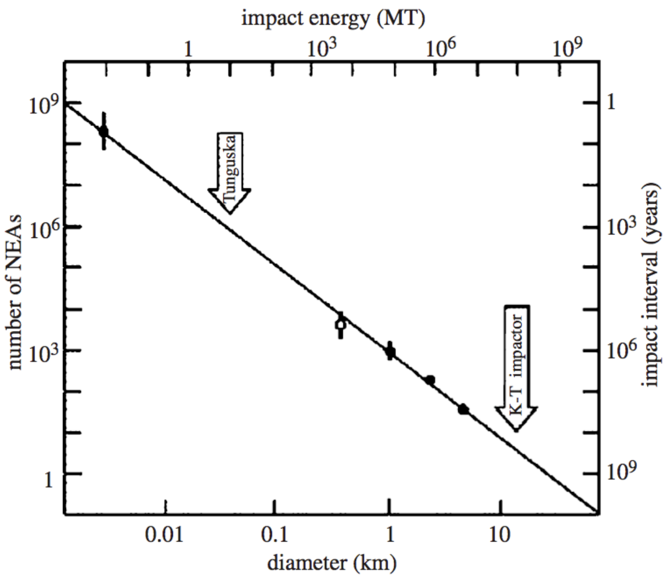


Figure 9: Correlation between the number of near-Earth asteroids, the interval between impacts, diameter of object, and energy of collision in megatons of TNT. Credit: D. Morrison[71]

NEOs of this size trigger a series of global effects: atmospheric heating due to re-entering debris from the ejecta plume which can cause firestorms and severe surface temperatures, ocean impact-induced tsunamis, and most importantly, global blackout due to suspended high-altitude particulates or "dust loading".[68,69,72] This injection of dust into the stratosphere would cause a significant reduction in solar insolation and an eventual drop in temperature characteristic of a polar winter, resulting in a "dark/cold catastrophe".[73] Such an "impact winter" would lead to enormous agricultural losses, with plants and herbivores dying in quick succession and carnivores left to starve.[68]

Surveys claim to have located only about one-third of these potential impact threats.[74] Although the annual likelihood of a large NEO impact is extremely low (approximately 1 in 100,000 million), such a catastrophic impact is statistically possible at any time and could lead to the extinction of humanity.[68–72]

Similar catastrophic climate effects are expected following disasters such as eruptions of supervolcanos. Besides the usual portrayal of red-hot lava and ash flow, experts predict "supereruptions" to result in "supersonic blasts of superheated, foamlike gas and ash that rise buoyantly all the way into the Earth's stratosphere, 50 km high."[75] Global climate will be affected for years in the same manner as an asteroid collision, with particles blocking most of the sunlight. Although ash does comprise most of the detrimental blocking for the first months, it is actually the sulfur dioxide (SO_2) which causes the bulk of the damage.[75] Reactions with oxygen and water yields sulfuric acid droplets (H_2SO_4) which nucleate and grow, creating a cloud of volcanic aerosols which persists for several years over most of the globe.[76] In addition, it is now thought that emitted volcanic gases create ozone holes in the atmosphere which allow dangerous ultraviolet radiation to reach the surface.[75,76] The end result would be a "volcanic winter" — a severely reduced surface temperature as the stratospheric aerosols absorb and backscatter the incoming solar radiation.[75,76]

Similar to an NEO impact, a food-supply crises would ensue in the case of a supervolcano, and it is possible that a "snowball Earth" type of climactic positive feedback would follow, leading to an ice age.[76] This appears to have been the order of events for the great Toba eruption in Sumatra more than 74,000 years ago,[75,76] with the resulting ice age lasting a millenium.[77] Supervolcanos are known to exist in several locations, one being Yellowstone, and humans are powerless to stop these impending eruptions.[75] The only thing we can do is prepare for the severe aftermath or remove ourselves from the situation — in this case, Earth.

Global climate effects of a nuclear war will result in much the same, with the smoke from burning cities spreading through the atmosphere.[76] Thus a nuclear exchange could result in a "nuclear winter" with subfreezing conditions persisting over much of the Northern Hemisphere for weeks to months.[76] It was calculated that the stratospheric loading due to the K/T extinction event would be similar to a "worst-case nuclear winter scenario."[73] Even smaller nuclear exchanges (100 to 1000 megatons[g])in urban areas will lead to massive smoke emissions and could trigger severe climate effects.[78] As Dwight Eisenhower stated in his first inaugural address, "Science seems ready to confer upon us, as its final gift, the power to erase human life from this planet."[79] Each of these disasters (NEO impact, supervolcano eruption, and nuclear exchange) result in a globally affected climate for weeks to years in which the "dark/cold catastrophe" would alter our way of life and perhaps challenge the continuation of human life on Earth.

2. Radical Climate Change

A more looming threat to terrestrial ecosystems and human existence is the possibility of severe and radical climate change. Over the history of Earth's 4.5 billion years, many factors have governed the evolution of the global biosphere including geological and climatic forces, extraplanetary events, and even life itself.[80] Humans, although existing for thousands of years, have only started influencing Earth's environment in the past few centuries.[80] The growth of the human population and the associated resource consumption have led to a current state in which anthropogenic changes to the Earth's ecosystems are on par with or even surpass those induced by other natural factors.[80] These changes include the large-scale perturbation of the global carbon cycle due to increase of carbon dioxide concentrations through industrialization and deforestation.[80]

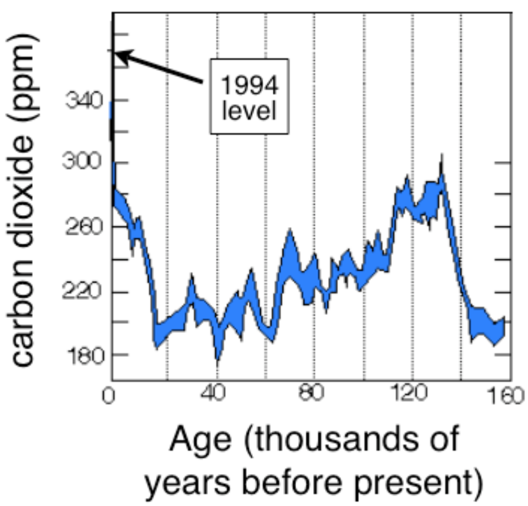
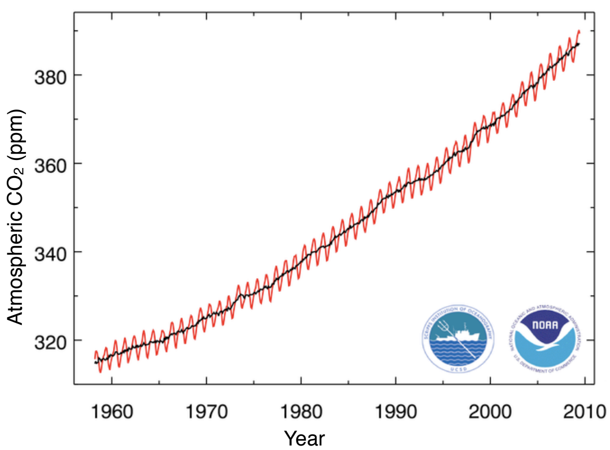


Figure 10: Gas bubbles trapped in glacial ice have been used as samples of ancient atmospheres, providing a record of how CO_2 has changed on a long-term scale. These results from the Vostok ice core (Antarctica) show natural variations associated with glacial periods; the 1994 atmospheric CO_2 level is higher than any concentration our planet has experienced dating back to the year 900 A.D. Credit: Take Part Social Action Network[81]

Ice core records indicate that over the last four glacial periods, the atmospheric CO_2 concentration remained and oscillated within a narrow window spanning 100 ppm until recent human activities drove the

[g]For reference, the Hiroshima bomb was approximately 13 kilotons. The total world nuclear arsenal in 1983 amounted to 12,000 megatons.[78]

value up above this range as seen in Fig. 10.[80] Atmospheric data taken at Mauna Loa, Hawaii from 1958–2007 show CO_2 concentrations to have a striking increasing temporal trend which is only the tail-end of a startling exponential increase as shown in Fig. 11a. The Environmental Protection Agency (EPA) states with virtual certainty[h] that the buildup of CO_2 and other greenhouse gases in the atmosphere is largely the result of human activities such as the burning of fossil fuels, and that increasing greenhouse gas concentrations tend to warm the planet.[82] This "greenhouse" effect already occurs naturally, with atmospheric gases absorbing solar radiation which has reflected off of the planet surface and is radiating back into space.[83] However, by burning fossil fuels such as coal, gas, and oil and by clearing forests, humans are drastically increasing the concentration of CO_2 accumulated in the atmosphere, the greenhouse effect is amplifying, and the Earth's temperature is increasing — hence the term "global warming."[83,84] The EPA states that global temperatures have increased 1.0°to 1.7°F in the period from 1906 to 2005[82] and that greenhouse gas emissions could cause a 1.8°to 6.3°F rise in temperature over the next century if atmospheric levels are not reduced.[83]



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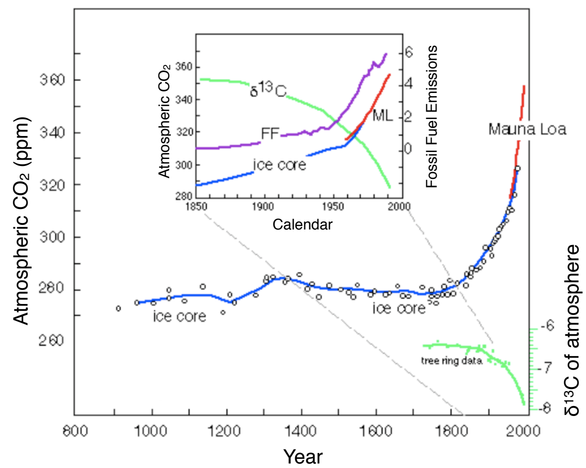

(b)

Figure 11: a) Recent measurements of atmospheric CO_2 from the Mauna Loa Observatory showing an overall increasing trend. The seasonal oscillations are due to plant activity in the Northern Hemisphere.[81] Credit: Scripps Institution of Oceanography/NOAA[85] b) Compilation of data from ice cores and Mauna Loa showing the known concentration history of atmospheric CO_2. The exponential growth in atmospheric carbon dioxide coincides with an exponential increase in fossil fuel emissions. In addition, the atmospheric carbon isotope ratio experiences an exponential decrease as expected if additional CO_2 is coming from the burning of fossil fuels. Credit: Take Part Social Action Network[81]

The climatological consequences of such an increase in global temperature are not fully understood, but it is thought that severe results will ensue such as extinction of more than a million species worldwide by 2050, an elevation of more than 20 feet in global sea levels which would devastate coastal and wetland areas worldwide (in addition to swamping the southern third of Florida and parts of Manhattan), an ice-free Arctic ocean and loss of shelf ice in Greenland and Antarctica, and frequent and intense droughts, floods, and wildfires.[82–84,86] Already, the evidence of global warming is overwhelming and undeniable; the flow of ice from Greenland's glaciers has more than doubled in the past decade, at least 279 species of plants and animals have moved closer to the poles, malaria has spread to higher altitudes, and the number of Category 4 and 5 hurricanes has almost doubled in the past 30 years.[84]

Although it is predicted that global warming effects will include 300,000 human deaths per year by 2050, the listed consequences don't seem to directly threaten the continuation of the human species, especially with "green" resources and technologies becoming more popular by the day.[84] There is current debate, however, as to whether climate change is progressing so rapidly that humans may soon be unable to reverse the trend — this has been coined the "tipping point".[86] Many scientists urge a reduction by half in global CO_2 emissions over the next 50 years to prevent the triggering of possibly irreversible changes to the global biosphere.[86] James E. Hansen, director of the NASA Goddard Institute of Space Studies, noted that Earth's

[h] "Virtual certainty" conveys a greater than 99% chance that a result is true.[82]

average temperature has risen nearly 1°F over the past 30 years, and that another increase of about 4°over the next century would "imply changes that constitute practically a different planet."[86]

Several positive feedback loops have already been identified by which increasing surface temperatures lead to a spiralling series of warmer and warmer temperatures. The cryospheric[i] albedo feedback system is one of these. Albedo is the fraction of solar energy reflected back into space, high for snow and ice (.7 to .9) as compared to the oceans (<.1).[87] Thus it is believed that in a warming climate, the cryosphere will shrink and the planet's overall albedo will decrease, allowing more solar energy to be absorbed by the surface and resulting in a warmer system.[87] In addition to the albedo feedback, melting permafrost will release CO_2 and CH_4, both important greenhouse gases, into the atmosphere, also leading to increased solar radiation absorption and warming.[87] A second feedback loop is the "runaway greenhouse effect" in which warming ocean temperatures lead to increased water vapor, a primary greenhouse gas, in the atmosphere which in turn result in increasing surface temperatures, thus leading to a vicious cycle of self-reinforcing warming.[88,89] It is believed that Venus experienced this sort of global runaway greenhouse effect about 3–4 billion years ago resulting in a harsh planet environment with no liquid water and surface temperatures of 752°F.[88–90] Some, like Dmitry Titov, the science coordinator of the Venus Express mission, warn that "Earth is moving along the curve that connects it to Venus," while others speculate that the Earth system will never undergo such a drastic atmospheric change leading to an inhospitable planet or that humans will be able to adapt to the new equilibrium.[86,88,89]

Although no one can prove with complete certainty that the current global changes are a result of human activity and the exact future state of Earth's climate system is impossible to predict, several points are quite clear.[82] Up to now, the planet's biosphere has been amenable to the development and sustenance of human life. Even if the current planetary changes are not anthropogenic in nature, humans have unquestionably affected the terrestrial biosphere (Fig. 12). It is uncertain whether the future state of Earth's ecological realm will include humans. As such, it behooves us to plan for the contingency in which humans will no longer be able to survive on the planet Earth.

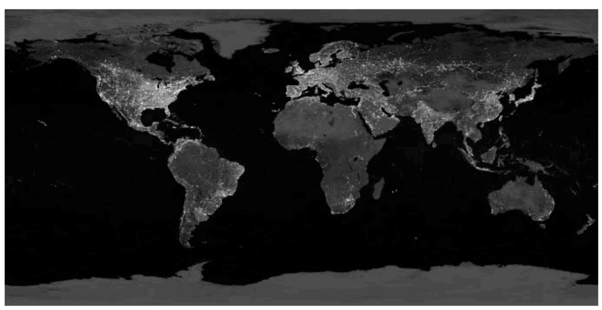

Figure 12: Earth city lights. Credit: NASA Goddard Space Flight Center[80]

3. Pandemics and Bioterrorism

Between 1347 and 1351, the Black Death (believed to be the Bubonic Plague) swept through Europe, claiming the lives of over one-third of the population (20–30 million people).[91] The Spanish Flu struck at the end of World War I, infecting 20 to 40 percent of the worldwide population and killing 50 million in 1 year, more people than were killed in the entire war.[91,92] In the 20th century alone, smallpox and tuberculosis are estimated to have caused around 400 and 100 million deaths, respectively.[93,94]

Pandemics, the global spread of sustainable human-infecting agents such as these, represent a serious threat to humans as made obvious by these past catastrophic incidences and others caused by cholera, typhus, measles, yellow fever, malaria, and leprosy.[95,96] Even today, pandemics exist and kill millions each year. The World Health Organization (WHO) stated in 2002 that tuberculosis kills 2 million people each year and estimates that between 2000 and 2020, nearly one billion people may be newly infected.[91,94] Acquired immunodeficiency syndrome (AIDS), which is the most advanced stage of HIV (human immunodeficiency virus), continues to devastate Africa with a projected death toll of 100 million by 2025.[97,98] Work on

[i]The cryosphere includes ice sheets, glaciers, snow, ice, permafrost, and seasonally frozen ground.[87]

sustainable HIV cures and vaccines has been slowed by the evolution of the virus into many strains, some of which exhibit drug-resistance.[99] Despite this, HIV is not considered a species-threatening event. Although its case fatality rate is close to 100%, HIV can remain dormant in the body for years and leads to a weakening of the immune system without killing the host directly.[97,99] The media-popular viral hemorrhagic fever-causing agents such as the Ebola virus (Fig. 13), whilst severe and highly contagious, are also not believed to threaten total eradication of the human species. Although cures and vaccines are not available, the short time between contamination and symptom onset (2 to 21 days) could allow adequate quarantine procedures to be carried out.[100] In addition, airborn transmission of these agents appears to be rare, although natural mutation or intentional genetic manipulation for weaponization must not be ruled out.[100]

Figure 13: The ebola virus. Credit: Centers for Disease Control and Prevention[101]

A continuing and substantial threat is influenza. This ancient microbe is said to have "appeared in millions of different forms over the millennia," producing devastating epidemics such as the Spanish Flu which occur at 10 to 50 year intervals.[91,102] Influenza exhibits two specific behaviors which, in combination, could lead to a swift and deadly spread of the disease before a suitable vaccine can be found and distributed: antigenic drift, evolution due to point mutations which leads to new strains not recognized by antibodies of previous strains, and antigenic shift, an abrupt and major change which produces new viral subtypes in humans, usually a result of direct animal-to-human transmission.[103] Recent (low-mortality) outbreaks include the 2004–2005 Avian Flu (H5N1) scare and the continuing 2009 Swine Flu (H1N1) pandemic.

Of course the most terrifying scenario is the unknown virus that emerges in a highly contagious, robust, and lethal form, traveling or mutating quickly enough to avoid suppression by vaccination, with an efficient transmission mechanism whether it be human-to-human or animal-to-human or both. Such a virus could already be in existence, slowing mutating into a "human-friendly" form; as stated by a professor of emerging viruses in Africa, "for every virus that we know about, there are hundreds that we don't..."[94]

Even more chilling is the realization that such a virus may be engineered to be used as a bioweapon. Bioterrorism, the deliberate release of viruses, bacteria, or other agents used to cause illness or death, has a long history dating back to the Middle Ages.[104–106] In more recent history, anthrax, glanders, and botulism have been intentionally released for the sake of causing illness and death, and advanced bioweapons programs have been discovered to exist in several countries including Iraq and the Soviet Union.[106,107] Smallpox remains high on the "danger" list; not only highly contagious and lethal with no known cure, smallpox was officially declared eradicated in 1980 meaning that vaccinations ended nearly 25 years ago leaving the public vulnerable.[108] Technology has now advanced to such a state that bacteria and viruses can be "weaponized", imbued with attributes such as safe handling, increased virulence, difficulty of detection, easy distribution and transmission, and resistance to current medicines.[104,108]

A global pandemic resulting from the release of a genetically engineered pathogen could be catastrophic. Stephen Hawking has said,[109]

> *The human race is likely to be wiped out by a doomsday virus...unless we set up colonies in space...The danger is that, either by accident or design, we create a virus that destroys us....I don't think the human race will survive the next thousand years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars.*

4. Disastrous High-energy Physics Experiment

Throughout history, man has performed experiments to further the understanding of the natural world. Experimental physics research has advanced in leaps and bounds since Newton's optical experiments with light and prisms in the late 17^{th} century to the current advanced experimental inqueries into particle physics.[110] Since the inception of accelerators in the 1920's, the energy of these experiments has increased by almost 11 orders of magnitude (Fig. 14), coinciding with the concern of unforeseen disasters.[111]

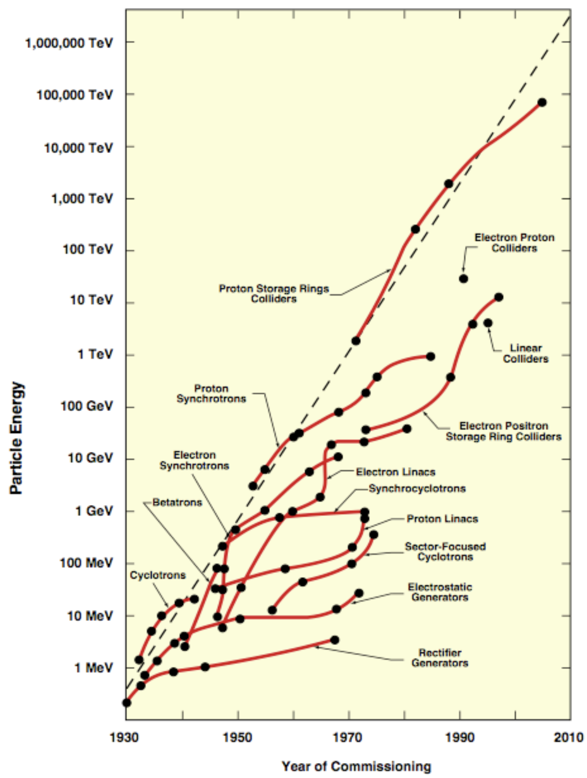

Figure 14: A "Livingston plot" showing the evolution of effective accelerator energy from 1930–2005. Credit: A. W. Chau and M. Tigner[111]

The launch of large-scale testing facilities such as the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in 2000 and the Large Hadron Collider (LHC) at CERN in 2008 provoked questions of safety to not only those in the area, but all of mankind. The three key doubts were the possibility of a) formation of a stable strangelet, b) initiation of a vacuum transition event, and c) the creation of a microscopic black hole.

Strangelet is the popular term given to small lumps of strange quark matter, which is a hypothetical state of matter consisting of large, roughly equal numbers of up, down, and strange quarks.[112,113] Theoretical studies suggest that accelerator collisions could produce stable strangelets which would be able to coalesce with normal matter, catalyzing the conversion into strange matter.[112,114] This would lead to the initiation of a chain reaction in which the strangelet would gather atomic nuclei, become increasingly massive, and accrete the whole planet, thus destroying Earth as we know it.[112,114] Several studies have allayed fears of a "strangelet takeover" dangerous to our planet by emphasizing two points. First, in order for such a thing to happen, at least 4 independent theoretical arguments (e.g., concerning stability and charge) would have to be simultaneously incorrect.[115] Second, "natural experiments" elsewhere in the Universe, on the Moon for example, where cosmic ray-induced heavy ion collisions occur at energies comparable to or exceeding those in laboratory experiments have shown that strangelets are not produced with disastrous consequences even after billions of years.[112,114–116] These arguments do not negate the possibility of such an event, but provide limits as to the probability that such a disaster might occur.

Secondly, it has been speculated that the Universe is not in its most stable configuration, and that a sufficiently violent perturbation could trigger a catastrophic phase transition of the vacuum to a lower energy state (Fig. 15).[115,117,118] In other words, if a critical nucleation event appeared somewhere in the Universe, this would give rise to a bubble of "real" vacuum which would expand into the current "false" vacuum at close to the speed of light.[115,117,118] "Vacuum decay is the ultimate ecological catastrophe; in a new vacuum there are new constants of nature; after vacuum decay...life as we know it [is] impossible."[119] Atoms would cease to exist, and the "true vacuum bubble" would engulf the entire Universe; "this would be a cosmic calamity, not just a terrestrial one."[120] Physicists determined that the current generation of particle accelerators would not be able to trigger such an event, based on observations of natural collisions in our past light cone (e.g., that we know of) that have not initiated the phase transition with more energy (10^{20} eV or 10^{11} GeV) than those occurring in the man-made experiments.[112,117,118,121] This does not preclude the existence of future accelerators which could reach such an energy level.[120,122] Furthermore, it is always possible that a very small non-zero probability of transition exists even with the current technology.[118]

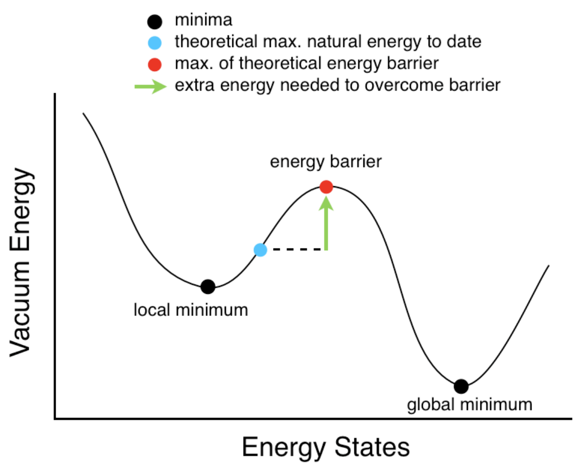

Figure 15: It is possible that the current vacuum state we live in is at a local potential minimum.[118] If such a metastable minimum is separated by a high enough barrier from the absolute minimum, it is possible that the naturally-occurring cosmic ray collisions in our past spacetime did not contain enough energy for such a transition.[118] Particle accelerators might provide an energy perturbation high enough to surmount this barrier.

The third fear is that high-speed proton collisions could create a black hole into which the matter around it would fall, thus destroying the Earth and all aboard.[120] This scenario has been refuted with arguments that should black holes be created, they would be microscopic and would decay too rapidly to accrete matter; any such creation would thus be harmless.[112,117,120]

Although these proposed risks have been studied and dismissed for the present generation of accelerators, the danger to mankind can not be disregarded. Not only are experimental energies ever increasing, but physicists aren't able to say with absolute certainty that several of these disasters have no probability of occurring. In addition, research and experiments are taking place for the exact reason that we don't actually know all the answers. Is there a different kind of disaster waiting right around the corner? As stated by Sir Martin Rees in *Our Final Hour*, "...we cannot be one hundred percent sure what might actually happen."[120] Are we willing to take that chance?

5. Astronomical Phenomena

In addition to the hazards of major Earth impact events, the universe holds a full hand of diverse and deadly phenomena ready to wipe out life on this planet. Gamma ray bursts and rogue black holes could wreak havoc at anytime, while incidents such as unstable planetary orbits and expansion of the sun are long-term concerns.

Gamma-ray bursts, intense bursts of gamma-ray radiation, are usually associated with special types of supernovae (extremely large ones nicknamed hypernovae) marking the death of super-massive stars.[123] Lasting up to several minutes, gamma-ray bursts are the most powerful explosions known in the Universe and it is thought that if one were to go off close enough to Earth, mass extinctions would be inevitable.[123–125] Although the zone of danger varies in the literature from hundreds to thousands of light years away, it is generally agreed upon that an Earth-focused gamma-ray burst would not only lead to direct irradiation of the planetary surface, but would severely alter the atmospheric chemistry resulting in ozone layer depletion which would allow solar UV radiation to permeate the atmosphere.[125–128] Studies show that the impinging gamma rays would dissociate the atmospheric molecular nitrogen (N_2) and the resulting nitrogen atoms, reacting with molecular oxygen to form nitric oxide (NO), would destroy the ozone (O_3).[124] Again, opinions on the immediate effects vary; some predict that the planet could be immediately sterilized by such a radiation event while others postulate that the instantaneous biotic effects would be limited to a brief UV burst and confined to the facing side of the Earth, but that the disruptive effects would be in the long-term and would include acid rain, global cooling, and radiation from the ozone layer depletion which could be lethal to many organisms including phytoplankton which is the basis of the marine food chain and valuable for oxygen production.[124,127,128] There is even some evidence that the Ordovician-Silurian extinction event 450 million of years ago might have been triggered by a gamma-ray burst.[124,127]

Death by black hole is another scenario in which life on the planet would end with little warning. Scientists recently suggested the existence of a class of intermediate-mass black holes which are easily ejected from their home globular cluster and become “rogue” black holes, stealthily roving the galaxy undetected and devouring anything in their path.[129,130] Although the chances of Earth falling prey to such a black hole is slim, the possibility does exist.[129,130] Neil deGrasse Tyson, director of the Hayden Planetarium of the American Museum of Natural History and eminent astrophysicist, says it like this: “In a contest between a black hole and the Earth, Earth would lose.”[130]

A long-term threat originating right in our backyard is the evolution of our star (the Sun) into a red giant. The Sun is currently in the main system of stars, meaning it is in the phase of its life (4.55 billion years old) where it is fusing hydrogen at its core with very little change in luminosity or radius.[131] This period of stability has been crucial to the development of life on Earth.[131] However, this can’t last forever. Core hydrogen will run out 4.8 billion years from now, and the center of the star will begin to contract due to gravity thus heating the outer shells and allowing a thick shell of hydrogen to begin fusion around the core.[131,132] The star will expand and the surface will cool and redden, giving this phase its name — red giant.[132] The expansion is expected to be substantial; the Sun will grow to approximately 200 times its current size and will eventually engulf Mercury and Venus. Whether or not Earth will be swallowed up as well is a matter of debate. Some believe that the Sun’s mass loss resulting in a weaker gravitational hold will allow the Earth to increase the radius of its orbit, while others show a tidal bulge on the Sun’s surface, caused by Earth and lagging enough to pull Earth back into the soup.[131,133] The verdict is moot, however, because long before that, maybe 1 billion years from now, the sun will have heated to such a point that the Earth’s oceans and atmosphere will boil off leaving Earth inhospitable to life.[131,134]

Another threat is the chaotic degeneration of the inner planet orbits in our solar system. The constant interplay of gravitational attractions between planets deteriorates the predictable motions into a disordered “melee” in which a Jupiter-Mercury resonance is established, Mercury’s orbital eccentricity increases to intersect the orbit of Venus, and a solar system catastrophe ensues with a plausible Earth collision finale.[135,136] Numerical integration of the equations of motion for the solar system have shown that there is a 99% probability that the “time to chaos” is on the order of 5 billion years, which is around the time the sun will be expanding into the inner solar system in any case.[135] It is that final 1% that we have to be worried about.

Each of these astronomical phenomena could threaten survival of the human species if we remain Earth-bound. As Sir Martin Rees has said “...humanity is more at risk than at any earlier phase in its history. The wider cosmos has a potential future that could even be infinite. But will these vast expanses of time be filled with life, or as empty as the Earth’s first sterile seas? The choice may depend on us, this century.”[120]

B. Utilizing the Moon to Maintain a Habitable Earth

Having discussed various paths leading to the destruction of a habitable Earth, the focus will now shift to several means by which the Moon may aid in maintaining human life on Earth. Since the development of humans, or *Homo sapiens*, around 200,000 years ago, we have remained Earth-bound in our manner of thinking. Having now entered the “Space Age” of our civilization, it is time to utilize available technology and our nearest neighbor, the Moon, to aid in preserving a safe and livable Earth.

1. *Outsource of Industries*

The first step might be to begin outsourcing harmful or dangerous waste products and processes such as pesticide and other chemical manufacturing.[137] These "toxic" industrial processes that are not consistent with preservation of Earth's delicate biosphere could be performed on the Moon. Another common proposal is storage of nuclear waste on the Moon.[138] Several ideas for the safe launch of the nuclear material exist, one being a suborbital reusable highly-reliable space plane which can launch off-the-shelf intercontinental ballistic missiles into space and to the Moon.[138] One further leap is the relocation of certain subgroups of society. For instance, it has been suggested that the dangerous/unwanted members of societies, convicts, the homeless, etc., should be settled in space colonies.[139] This idea, providing protection from those people deemed unsafe or unfit for interaction with society, is most commonly found in science fiction, but there is precedence: the colonization of Australia began with the transport of criminals. The economic feasibility has yet to be proven, however.

Ideas such as these have been decried on the basis of dangers of launch and polluting the Moon and will continue to be hotly debated. Proper safeguards and precautions would have to be set to allow for a lunar future beyond that as a waste repository and industrial plant and to maintain the safety of those on Earth. Obviously "polluting" the Moon in this manner is not an ideal situation, but if the alternative is allowing waste and toxins to build up and remain a hazard on Earth to the detriment of human health and life, the choice is clear.

Besides outsourcing harmful waste and processes, there might come a time when space on Earth grows even more precious, and necessary but space-consuming industries such as energy production, food production, and solid waste disposal will be displaced onto the lunar surface. Lunar export has been touted, sometimes tongue-in-cheek, as a solution to solid waste disposal, a serious issue of our time which only promises to become more of a problem as time goes on.[140] Certain energy productions, mainly solar and nuclear, would be not only possible on the Moon, but would even provide an advantage: solar energy from the sun would not be dissipated by an atmosphere as on the Earth, and nuclear plants could be built and operated with less fear of radiation hazard to populations and spread through the atmosphere in the case of an accident. Studies on lunar solar power show that the Moon receives more than 13,000 terawatts of solar power, only 1% of which would satisfy Earth's needs.[141] To "beam" the energy back to Earth, the solar energy would be converted into microwaves which could be beamed to thousands of receivers around Earth and then converted into electricity; successful Earth-Moon power beams have been used before so the technology exists, but efficiency of transmission still requires improvement.[141]

Figure 16: Biosphere 2. Credit: University of Arizona[142]

2. *Develop Closed-Loop Systems*

Ideally, humans would be able to live on Earth with absolutely no impact on the environment, resources, other life, etc. A side benefit of space technology created for future manned Moon and planetary missions would be development of "closed-loop" processes that could be implemented on Earth. Controlled Ecological Life Support System[143] (CELSS) habitats such as BioHome,[144,145] Biosphere 2[146,147] (Fig. 16), and BIOS-3[143,148] have been created, tested, and improved upon since the early 1970's. These studies have focused on waste water and air treatment, and maintaining closed ecological systems in order to support humans for years at a time. Other studies have also considered waste incineration products for crop production and radiation effects.[149–151] Although successful in many ways, each of the CELSS projects has faced certain failures and drawbacks. A total closed-loop system is not necessary for a lunar base since periodic "infusions" from Earth are possible; however, as we work towards the ideal self-regenerative life support system in preparation for future long-term planetary expeditions, implementing such technology advances will lower our impact here on Earth as well.

3. *Provide Early Warning Observations*

A habitable and safe Earth implies forewarning of threatening space phenomena such as catastrophic asteroid impacts. A permanent lunar observing platform might be better situated to observe such space hazards and to give adequate time for preparation. An anticipatory indication of other troublesome incidents might also be possible: coronal mass ejections and strong solar wind streams tend to generate geomagnetic storms and can affect power grids, GPS, radio communications, and satellite disruptions.[152] Section III.A describes the Moon as a vantage point for astronomical observations; these advance warning observations would fall in the same category.

4. *Ameliorate Overpopulation and Resource Depletion*

With human population likely to reach a population size by the year 2050 of between 8 billion to 11 billion from today's 6.7 billion[j] (a doubling of the world population since 1950), resource depletion is becoming a significant worry, specifically in regards to fresh water, food, and non-renewable resources.[154,155] The fourth Global Environmental Outlook report (GEO-4) released in 2007 from the United Nations Environment Programme warns that "we are living far beyond our means."[156] The report of the 1992 United Nations Conference on Environment and Development states that "the growth of world population and production combined with unsustainable consumption patterns places increasingly severe stress on the life-supporting capacities of our planet."[155]

This notion that Earth may have a limited carrying capacity has been postulated since the 17^{th} century[155] and was popularized as the Malthusian catastrophe in which population growth outpaces food production and general resource capacity and famine, death, and civilization collapse ensue. A compilation of numerical estimates of Earth's human carrying capacity show a range from under 1 billion to more than 1,000 billion; alarmingly, the median falls around 10 billion, a population we are expected to reach around the year 2200.[155] Although many believe that new technologies and the spread of sustainable practices will outweigh the extra resource growth, the Secretary-General of the UN states that "it would be foolish to count on them and to continue with business as usual". The truth is that our planet Earth may be unable to keep up with human population growth and resource utilization. Already, quality of life has stagnated or diminished in certain regions due to lack of life-sustaining resources such as fresh water, and violent conflicts have arisen over these issues.[155,157,158]

How can we plan our future to avoid this dead-end paradigm? One answer is — the same way the Europeans did in the Middle Ages, the same way the Polynesians did, the same way mammoth-hunting tribesmen did, the same way the Americans who settled the West did, and the same way we always have — through exploration and discovery of new lands with new resources. As we gobble up Earth's resources, the next new land is off-planet, and the nearest new continent is the Moon.

Spreading our civilization into space has long been proposed as a solution to the population and resource problem. With an almost unlimited carrying capacity, human population would be able to grow beyond the narrow constraints imposed by Earth. In addition, severe resource depletion on Earth might be countered by importing materials from space using the Moon as a commercial port as described in Section VI. Of course, new technologies and much research will be required to provide feasibility, but it might become necessary in the near future. As Malthus himself wrote, "The germs of existence contained in this spot of earth, with ample food, and ample room to expand in, would fill millions of worlds in the course of a few thousand years."[159]

5. *Develop Nature Preserve*

With biodiversity dwindling by the day, seed vaults, secure stores of plants, have been proposed and implemented in several sites around the planet.[160] The aforementioned threats to life on the planet Earth lend credibility to the idea of a lunar seed vault, removed from these risks and available for a new floral beginning if ever necessary.

[j] The world population was estimated at 6,774,529,635 people at 3:58 GMT (EST+5) on July 31, 2009[153]

Taking the idea of Earth preservation to the extreme is the future development of Earth as a biopark or nature preserve. A recent study by the World Conservation Union lists one third of marine mammals and one quarter of land animals as officially threatened by extinction.[161] The U.S. Fish and Wildlife Service lists 612 American animal and 746 American plant species as endangered or threatened.[162] Many of the causes are human-related: pollution, fishing, habitat destruction, and hunting. A less radical concept than complete removal of humans from Earth to protect wildlife and nature is the concept of an "island civilization" in which human civilization would occupy only about two percent of the land mass.[163] A reduction in world population from 6 billion to 1.5 billion is suggested, as Paul Ehrlich and several others have determined that at this level, a high quality of human life can be balanced with a sustainable future with other life forms on Earth.[163] This would allow a portion of the human population to remain and live in symbiosis with Earth, while the remainder of our civilization moved towards the stars.

We believe that our survival as an Earth-bound species is by no means assured and that a supplemental human presence beyond our planet is required. The Moon is proposed as a means to maintain and even improve quality of life on Earth, and is suggested as a stepping stone to future human civilizations amongst the stars. Al Gore, in his documentary *An Inconvenient Truth*, poses it this way:[164]

> *You see that pale, blue dot? That's us. Everything that has ever happened in all of human history, has happened on that pixel. All the triumphs and all the tragedies, all the wars all the famines, all the major advances... it's our only home. And that is what is at stake, our ability to live on planet Earth, to have a future as a civilization. I believe this is a moral issue, it is your time to seize this issue, it is our time to rise again to secure our future.*

Figure 17: Earth. Credit: Space Today Online[165]

VI. Commercialization

Congruous with the accidental discovery of the Americas during the search for a shorter path to Asia and its riches, and akin to the rapid European colonization of the newly-discovered continent for its land, resources, and potential, commercialization is sure to be a driver for future human activities on the Moon. As described in the following sections, the huge expansion in commercial opportunites related to a human presence on the Moon will open up entirely new industries and create new technologies, will boost economies world-wide, and will generate new employment opportunities.

A recent study shows that future commercial opportunities on the Moon are already becoming apparent. Research of the competitors for the Google Lunar X Prize predict a market value in excess of $1 billion over the next decade in the areas of services and hardware sales to the worldwide government sector, products provided to the commercial sector, entertainment, sponsorship, and technology sales and licensing.[166]

Almost by definition, commercial development of outer space will require private investment. As is more clear in these fiscally difficult times, government investment alone cannot, and in a free capitalist paradigm perhaps should not, effectively lead to regular commerce at our nearest celestial neighbor, the Moon. Once the possibility of profitable commerce becomes apparent, even in the distant future, private investments will begin to turn the tide on our 40-year abandonment of the Moon.[167] A sampling of organizations that advocate commercial exploration of the Moon include the Space Frontier Foundation,[168] the Millennial Project,[169] the Artemis Project,[170] competitors for Google Lunar-X Prize,[171] and the Space Studies Institute.[172,173]

A. The Moon as a Commercial Port

Just as it is a stepping stone for exploration of the solar system as discussed in Section II, the Moon is also ideally situated as a port for further commercialization of outer space. A major advantage of the Moon as the first "other" world we inhabit is its proximity to Earth as compared to Mars and asteroids. In addition, the Moon holds many of the resources needed to develop future space infrastructure.[174,175] Raw materials on the Moon could be utilized to more inexpensively build the infrastructure of a permanent manned presence in space, including the hardware needed to go to Mars and beyond.

In addition, as we bring resources to Earth from outer space, the Moon would make an ideal staging area and locale for inspecting, purifying, and quarantining goods prior to delivery to Earth. For example, it has been shown that various near-Earth asteroids (NEAs) are rich in substances such as gold, diamond, uranium and other precious metals.[176] It could be dangerous to bring material from an NEA directly to Earth due to collision, infection, and/or radiation; but utilizing the Moon as an intermediary port would allow these risks to be mitigated by processing, inspection and quarantine. In effect, the Moon could become a space port for Earth's commerce with the rest of the Solar System.

Admittedly, transporting goods between the Earth and Moon is extremely cost-prohibitive at present. However, movement of goods from the Moon to the Earth need not always be as expensive, once the proper infrastructure is in place. Several proposals for product return systems include: solar-powered magnetic launch rail systems, space elevators, or conventional aeroshell and parachute entry, descent, and landing techniques.

B. Earthly Benefits: Products and Technologies

From a historical perspective, there were numerous products that were invented or accelerated by our first race to the Moon. A recent web article describes "10 Gifts from Apollo" as the commercial legacy of the first space race.[177] These included wireless headsets, memory foam now used in everything from helmets to beds, cordless battery-powered tools, flame resistant materials and clothing, industrial cooling suits, human fluid recycling machines used for kidney dialysis, compact exercise equipment, metalized materials used in everything from mylar balloons to attic insulation to survival blankets, freeze dried food preservation, and scratch resistant lens coatings. Certainly a new move to commercialize and permanently inhabit the Moon would lead to even greater numbers of useful products here on Earth.[178]

We can expect a certain amount of development and economic stimulation from the very act of preparing for the journey and permanent residence on the Moon, as well as from the struggle of coping with unforeseen circumstances once we make the attempt. As they say, necessity is the mother of invention; the problems of living in space will force us to invent around them. Some examples follow.

1. Conservation and Recycling Technologies

As humans move to inhabit regions of outer space, conservation and recycling of supplies will become more and more important as the length of stay increases. Development of the early space missions to the current International Space Station have proven that recycling of even such fundamentals as water and air becomes critical for mission sustainment. As we move to the surface of planetary bodies, including the Moon, and towards "permanent" outposts, creation of our own closed-loop systems to recycle non-local (mostly volatile) resources will remain critically important. This will presumably take a great deal of invention, engineering, and practice. This development will pay dividends with greater efficiencies here on Earth.

As explained in Section V.B, there is a risk to the overuse of natural resources due to increasing population and industrialization. If we can "close the loop" with our homes, office buildings, and other earthly habitats, we will drastically reduce our impact on the Earth's environment, and as a result, increase its carrying capacity (not to mention preservation of its natural beauty). If such recycling hardware, or even full closed-loop structures, can be moved to assembly-line production, these new products can create an economic boom, or at least a new standard driving replacement of less-efficient structures.

2. *Efficiency Drivers*

The drive towards extremely high efficiency for lunar development equipment may also lead to new advances here on Earth. As power and resources have become more scarce, and by the law of supply and demand correspondingly more expensive, the need for efficient commercial activity has already grown. This has led human activity to treat these scarce resources with care, allowing us to do much more with less as advocated by R. Buckminster Fuller in his provocative "Utopia or Oblivian."[179] The Japanese, having a very vibrant commercial society on a relatively small land mass (and few resources relative to their population), were early masters of efficient use of resources. Likewise, as humans move to colonize space, we will be forced to become highly efficient with very scarce resources. We will have to develop new processes that conserve these scarcities. As with recycling, these new processes will in-turn improve resource utilization back on Earth, and help prolong and preserve our resources here.

3. *Lunar Dust Technologies*

Solving one of the biggest environmental problems on the Moon may also help us solve problems here at home. It may come as a surprise to most people that one of the largest obstacles to colonizing the Moon is dust "pollution." The Apollo astronauts discovered that lunar dust caused a multitude of problems for them. Lunar dust has formed from billions of years of meteor impacts into the Moon's surface. With no water, wind, or other natural weathering, the lunar dust is extremely sharp and abrasive. The Moon also has no natural processes, like surface volcanization or sedimentation, to recombine these smaller particles into larger masses, so the dust is very fine. Finally, as there is no surface water or air to discharge the buildup of static electricity, the particles have clung to everything we have placed on the Moon. As a result, the Moon is mostly covered meters deep with fine, abrasive, electrically-sticky dust.[180] However, some have indicated that this fine powder is relatively ready for processing, and may make early mineral process mining on the Moon easier.[181]

The astronauts believed this dust would be the most difficult issue to overcome in establishing a long-term lunar development. It ruined a great deal of Apollo equipment, irritated the astronauts' skin and eyes, smelled badly, and actually endangered their lives by abrading the seals on their space suits.[182] However, learning to deal with this dust on the Moon has clear commercial benefits here on Earth. In modern times, dust and other pollutants on Earth are a growing issue. Modern industrial processes, mining, agriculture, deforestation and desertification have led to increased particulate content in our air.[183]

As a prime example, the industrialization of modern China has caused a vast increase in the number of coal burning power plants there. In larger Chinese cities, it has become unusual to see the blue of the sky on most days because the air is so choked off with coal particles and industrial smoke. This pollution has caused a decrease in the life expectancy in China.[184] As we are forced to develop technologies to master prevention of dust penetration into our work and living areas on the Moon, and even to mitigate its effects on our bodies, these same technologies will have a huge market for environmental and personal health here on Earth. Furthermore, as we move to colonize other celestial bodies, such as Mars and near-Earth objects, we will face similar dust problems that need to be overcome. Again, the Moon will serve as a better place to develop, practice and experiment with these technologies than more distant locations, as resupplies and emergency medical care and retreat are relatively close by, here on Earth.

4. *Safety from Radiation*

The Earth and the Moon share another environmental danger that needs to be overcome — solar radiation. Skin cancer is on the rise here on Earth.[185] As most people know, the radiation risk on the Moon (as well as any other celestial body without a significant atmosphere and magnetic field - i.e., Mars and near-Earth objects), poses cancer risks several orders of magnitude higher than the Earth. In fact, during a solar flare storm, a human outside of Earth's protective magnetosphere would face a significantly decreased life expectancy. Research has shown that a layer of lunar regolith only a couple of meters deep is sufficient to protect humans from most radiation threats on the Moon. More serious threats, such as large solar storms, would require greater depths, but deeper "storm shelters" would still be effective.

That said, much of the utility of going to the Moon will be achieved in the exploration of its surface features, such as lava tubes, valleys and mountains. Humans will need more mobile protections than several meters of regolith. This will call for improved internal medications, skin creams, protective clothing, and even more exotic protection methods. Internal medications will be developed to help prevent and recover from radiation exposure. Already, there are nutrients that can be taken to help aid burn recovery and ameliorate the effects of radiation, such as vitamin K, beta carotene, and iodine. Skin creams and sun screens are already being developed to fight a broader range of solar radiation, such as UV-A and UV-B. Finally, there is clothing that is being designed with sun-screen capabilities built into the fibers. Preparing for long-term stays on the Moon will drive development of these technologies to the extreme. Again, these new developments will, in turn, find ready markets here on Earth to fight the growing skin cancer rates.

Although lunar-based commercial efforts will no doubt improve life for those on Earth in the myriad ways described, we believe that, as historically demonstrated, the most valuable and beneficial products and technologies haven't even been imagined yet. It will take a giant step on our part, but the rewards are bound to be immeasurable.

C. Moon-based Product Development and Manufacturing

Commercial endeavors could derive benefit from lunar characteristics and conditions. The following sections make a case for manufacturing and product development on the Moon.

1. Lunar Product Development Laboratory

Even beyond the products we develop for the journey, the Moon itself will provide product development laboratory conditions that are unmatched and will likely lead to new products. Past and current manufacturing exploits have been molded for Earth physics and conditions, but future ventures and industries will have the advantage of opting for a lunar setting. Research in a literal vacuum will become easy and affordable. New ideas for low gravity applications will come naturally for those who live there around the clock. Over the relatively short space age we have already experienced with its relative short-term exposures to the "space environment," there has been significant commercial interest in space-borne product research and development. For example, the growth of industrial crystals with different geometrical shapes than are possible on Earth can be grown in low gravity, vacuum conditions.

The Moon provides a superior product development laboratory to space stations and other celestial bodies for several reasons. As already noted, it is closer than Mars or asteroids. Compared to orbiting laboratories, longer term experiments would be possible on an established lunar base. It would be easier to establish separation from other experiments to ensure vibration free environments or other unique conditions required for each experiment. On the Moon, there would be room to grow, build, assemble and test devices like solar panels. Experimentation on the Moon could include local resources, such as initiation of greenhouse agriculture using local soil. Ultimately, as industrial production itself reaches the Moon (manufacturing of glass labware from local materials, for example), lunar experimentation will be accomplished with vastly lower launch costs than experimentation done in orbit.

Unlike satellites, the Moon provides an environment like that of the rest of outer space because it lies outside Earth's protective magnetic field. Satellite research facilities, like the International Space Station, are in a much lower radiation environment, still shielded by Earth's magnetic field. Thus, the Moon provides a superior research environment to examine the effects of deep space, including cosmic and full solar radiation, solar storms, etc. Again, our ability to learn and practice protection from these perils, as well as the potential to develop technological products for further out in space, makes the Moon a superior location for a product development laboratory.

2. Manufacturing for Earth

There are distinct environmental conditions on the Moon which may be advantageous for certain manufacturing processes, including low gravity, vacuum, extreme thermal conditions, and few repercussions to toxicity. Manufacturing processes requiring these conditions are currently performed on Earth at expense and even sometimes risk to employees. Moving such operations to the Moon would ameliorate these problems.

At about one-sixth gravity, heavy manufacturing processes require less power, and with six times the strength against gravity, humans can easily lift and maneuver objects in the 100-kilogram range. This has obvious advantages for lunar-based construction processes.

Several higher-tech manufacturing processes, like material deposition circuit printing and aluminum welding, are performed well in a vacuum environment. With the relatively high-vacuum environment of the Moon as a “reservoir”, it be much easier, faster, and cheaper to prepare a vacuum chamber for such industrial processes.

With the increased debate over global warming and increased awareness over the effects of pollution on Earth’s delicate biosphere, “dirty” manufacturing processes are becoming an ever-increasing problem. Our “exportation” of polluting processes to China by simply importing from China those goods previously manufactured in the US is at best a short-term fix. We are already starting to see toxic materials in imported goods from China along with a decrease in Chinese life expectancy and documented air and water pollution.[186] Assuming that toxic output cannot be sustained for an unlimited time in a limited and fragile biosphere, what choice do we have? Export our polluting processes to the Moon, where “dead” craters and lava-tubes can be utilized to sequester toxic by-products.

The Moon offers a variety of thermal conditions for manufacturing processes as well. In direct sunlight at lunar mid-day, the temperature averages 107°C, while during the lunar night, the temperature drops to −153°C.[26,27] While these temperatures have a downside of a 14-day on-off cycle at the equator, manufacturing processes requiring either of these extremes could take advantage of these local ambient conditions nearly 50% of the time. On the other hand, only a meter below the lunar surface the temperature is steady at about −35°C nearly all of the time.[187] Temperatures at the poles are colder (40°K), but more stable than the equator. For processes requiring a more moderate temperature range, the temperature swings (as well as radiation) can easily be avoided by utilizing the natural insulation of the lunar regolith. Likewise, for the processes requiring more extreme temperatures, the subsurface temperature “reservoir” can be used during the 50% off-cycle time. There is a possibility that the increased radiation exposure itself could be used for some manufacturing processes such as curing and etching.

D. Commercial Use of Lunar Resources

Much of what was addressed in Section II.A applies also to commercial utilization of lunar resources. In that section, we focused on In Situ Resource Utilization as a means to reach farther destinations in the solar system. In this section, we address the commercial potential of lunar resources. Because they were already introduced, we present only a brief description of the commercial use of these lunar resources:

- Oxygen is an important commercial product for respiration in future lunar habitats. While it may now seem awkward to consider purchasing the very air we breath, the same argument was once made about water, which is now found bottled in every supermarket. Other uses of oxygen include propulsion oxidizer and other industrial processes requiring a refined oxidizer. Finally, oxygen is a key reactant in fuel cells.

- As with everything used in space, economic calculations will be performed to decide whether it makes more sense to bring solar cells from Earth or make them from the silicon found in lunar regolith. Considering the large quantity of cells that will be required for permanent habitation and commercial activities on the Moon (and other locations from which we use the Moon as a stepping stone), as well as the enormous cost to launch each kilogram ($10-15,000), there will be a calculable mass of cells for which it makes more sense to launch the manufacturing equipment rather than the end product cells. Ultimately, in the distant future, silicon can also be used for the manufacture of computer chips and microprocessors.

- There is great value to the rare elements, precious metals, and minerals that are available on the Moon in more abundant quantities than those on Earth.

- Once there is commercial activity on the Moon, generation of power will be necessary. It may then be possible to beam this energy back to Earth. While there is wide discussion about beaming energy back to Earth from space-borne sources, the real commercial use of power in space will be to sell and use that power in space, not on Earth. Again, the relatively high cost of launching fuel, batteries, and other power sources to the Moon, makes any potential power source on the Moon worthy of study.

- The commercially interesting thing about heavy helium is that it is a leading candidate for fueling future nuclear fusion power plants. If and when nuclear fusion becomes a viable technology here on Earth, this abundance, along with the vast amount of energy that can be released from relatively small mass of reacting heavy helium, may make it commercially profitable to mine helium from the Moon and return it to Earth as a fuel for nuclear-fusion power plants. Likewise, fusion plants could later produce power on the Moon itself or for other vehicles utilizing the Moon as a stepping stone for further exploration and activity.

E. Tourism and Adventure

Trips for the wealthy and privately-sponsored will provide seed funding for lunar development. Tourism has already demonstrated itself to be a potentially lucrative commercial enterprise in space, fetching tens of millions of dollars for a wealthy adventurer to make a trip. It is predicted by some that the first commercially viable private businesses on the Moon may be a hotel, although most references found have been written with jest in mind (e.g., Lunar Hilton Hotel).[188,189] Private tourists will head to the Moon for adventure, for exploration and scientific discovery, or even just for the ultimate solitude.

For those who can't afford to make the actual trip, there will be opportunities to be a virtual tourist. We will be able to drive our own lunar rover from a virtual reality suite on Earth, although we would need to cope with three second communication latency. Broader public exploration can take place through web applications like Google Moon.[190] With its map utility, this will allow us all to go poking around newly explored lunar craters and lava tubes or examine the recent state of the Apollo landing sites.

The potential is endless. Imagine LunarDisney, or the first McDonalds on the Moon, or the ratings of the first Lunar Olympics. Television advertising could be a strong potential source for lunar development. China recently spent several years worth of NASA budgets to put on an Earth Olympics, so this clearly generates cash and spending. While it may be pretty far into the future, Olympic events in glass domed arenas would be spectacular, with pole vaulting and high jumping taking on near-flight proportions. Only the limits of imagination would hold back the interesting events we could watch and even participate in as tourists.[191,192]

F. Real Estate

As described above, there are a vast number of potential commercial and industrial endeavors which could develop on the Moon. These may take decades, or even centuries to establish, but considering the accelerating pace of technology, as exemplified by Moore's law and human kind's inherent desire to explore and colonize as described in Section VII, there is little doubt in the minds of these authors that colonization and commercialization will some day be planted firmly in lunar soil. There will be science stations, factories, supply stores, space ports, hotels, and even private residences.

At some point, probably after the real and virtual tourism have developed regular routes of transportation and local infrastructure for survival, people will begin to take up long-term or even full-time residence on the Moon. As discussed in Section IV, heritage treaties prevent such ownership of lunar property, but future commercialization might sway the politics of such laws. The potential price for such an opportunity boggles the mind. What would someone pay to sit on their own domed balcony to watch the Earth-rise or Earth-set. Where would someone place the ultimately safe nuclear bomb shelter? What would it be worth to start a new chapter in human evolution, by starting to raise successive generations is distinctly different environmental conditions? What would it be worth to our species to ensure that a killer asteroid or other cosmic event did not exterminate us? What will the first eccentric person be willing to pay to be the first resident of the Moon, the first interplanetary citizen — billions?

G. Commercialization Incentives

While tourism will provide the incentive for the elite to invest in going to the Moon and virtual tourism will provide the vehicle for others to visit, this all does not ensure enough infrastructure to initiate the breadth of lunar commercialization discussed above. There will need to be a greater incentive than "the thrill of it" if we want permanent habitation and commercialization of the Moon. History may provide some suggestions.

Historically, privately funded exploration and development of infrastructure came with the encouragement of a potential profitable payoff. One of the primary modes of this payoff was the ownership of newly claimed land. Examples of payoff driven expansion include:

- development of the spice roads into Asia to gain spices and exotic goods
- development of paved roads across the Roman empire to give Rome access to the tribute and goods of the outer territories
- development of shipping between Europe, Africa and the Americas to gain gold, cotton and other agricultural products
- development of wagon train routes across the American west to gain land and gold
- development of the American railroads to gain the profit from shipping products, as well as government incentive payments.

In the case of initial settling of the Americas, it is worth noting that far more goods returned to Europe from the commercial and industrial development in the new continent than were ever shipped there to establish settlers.

These examples could be particularly applicable to building lunar infrastructure. Great quantities of land were given to western settlers by way of the process of homesteading. That is, a settler could stake a claim on an unclaimed plot of land by filing a document with the local government office. If the settler made an improvement on the land every year for five years, the rights to the property would be perfected and the settler would be vested with full ownership rights. This process was still in effect in parts of Alaska well into the 20^{th} century. A parallel process of rewarding lunar real estate could be used to encourage private infrastructure on the Moon.

Similarly, the railroad companies that raced across the western United States were given not only government payments for every mile of track they laid but also significant parcels of land on alternating sides of their tracks as payment for developing transportation infrastructure. This newly granted land became even more valuable in the process, as it had prime access to rail lines and thus inexpensive transportation for the flow of goods to and from the land.[193] Again, in a parallel fashion, land for space ports could be granted on both the Earth and the Moon for the companies that establish regular commercial transportation between the first seven continents and the newly developing eighth continent that the Moon will become.

In sum, the best encouragement to commercially develop the Moon and its transportation and other infrastructure can be the same reward previously used to encourage development of "new" land of the Earthbound continents, ownership of some of the land itself. In fact, it would be unreasonable to expect any private venture to develop transportation or other lunar commercial activity if they could not own the land necessary for the development. As described in Section IV, interpretation of current international treaties regarding the Moon and Space indicate that it is not currently possible for individuals or entities to own lunar territory.[194] Thus, even if governments are unwilling or unable to invest adequately to development the Moon, they could potentially accomplish even more by reshaping policy and international law to encourage private development and ownership of resources in space.[195,196]

Initiating commercial activities on the Moon unquestionably is going to be extraordinarily expensive. However, once this infrastructure is in place, future manned space development will become more affordable, we will have learned how to live with the help of local resources, and direct products and technology spin-offs will have improved life on Earth as well.

VII. Innate Sense of Exploration and Discovery

> *We set sail on this new sea because there is new knowledge to be gained, and new rights to be won, and they must be won and used for the progress of all people…We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win...*
> *— John F. Kennedy, 1962*[197]

It is believed by some that such an endeavor is more than justified merely through the conviction that "we can." Thousands of years of human development leading to the advancement of science, engineering, and technology have led up to this point — an era of history capable of reaching other cosmic spheres — is now the time to halt our progress? John F. Kennedy's momentous speech ended with the following: "Many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, 'Because it is there.' Well, space is there, and we're going to climb it, and the moon and the planets are there, and new hopes for knowledge and peace are there. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked."[197]

Still others believe that the current generations have an obligation to those forthcoming — an obligation to guide our civilization into space — an obligation to secure the future of humanity while it is still possible, before progress and technology and enlightenment are engulfed in the ensuing darkness and degeneration of human development. Martin Rees, England's Astronomer Royal, asserts it thus: "Once the threshold is crossed when there is a self-sustaining level of life in space, then life's long-range future will be secure irrespective of any of the risks on Earth...Will this happen before our technological civilization disintegrates, leaving this as a might-have-been? Will the self-sustaining space communities be established before a catastrophe sets back the prospect of any such enterprise, perhaps foreclosing it forever? We live at what could be a defining moment for the cosmos."[120]

Arthur C. Clarke was one of those who believe that humans are at their best when pursuing their curious inclinations and when being challenged. Perhaps this venture into space and the beyond will prevent stagnation and collapse of our civilization. As he stated, "The crossing of space may do much to turn men's minds outwards and away from their present tribal squabbles. In this sense, the rocket, far from being one of the destroyers of civilisation, may provide the safety valve that is needed to preserve it."[198]

We, the authors of this work, believe that there is something further compelling us to take this giant leap into space. We have come to recognize that there exists an inherent nature of man, "a universal instinctive drive deeply ingrained in all living creatures", pushing us to learn — to explore — to discover.[199] Of the fundamental questions we ask as human beings, there is none so simple, yet profound and necessary for even the youngest among us, as "Why?" Perhaps it is what makes us unique as a species — that desire to dig deeper into root causes or understand longer term implications. "Humanity must rise above the Earth, to the top of the atmosphere and beyond, for only then will we understand the world in which we live."[k,200] It is not only the understanding of the world in which we live that we seek, but ultimately the question of life itself. Why are we here and what is our purpose?

While this question is outside the scope of the current paper, this at least we know to be true — we are explorers at heart. There is no other species who has sought to live on every continent on this planet. From the first trek of *Homo erectus* out of Africa more than a million years ago to the colonization of the Greeks in the ancient Meditteranean and that of the Vikings in the North Atlantic, from the maritime expansion of the Chinese to the succeeding European Age of Exploration, humans seem destined to expand and migrate to the far reaches of the globe.[139] We seek to learn how to live wherever we can, regardless of how inhospitable the terrain; from the yurts in northern Siberia and the igloos of the Arctic, to the dry dusty plains and deserts of Australia and equatorial Africa, down to the south pole itself, and every climate in between. Perhaps it is long-term survival that drives this wanderlust of the human species, or perhaps it is this wanderlust, this desire "to strive, to seek, to find," that has and will drive our long-term survival.[201]

Either way, the contributors to this work are a part of an unknown fraction of the human population that takes the view that the "history of man is hung on a timeline of exploration, and [space] is what's next".[202] With imaginations alight, we dream of a time when people can rise from the Earth to voyage amongst the stars and dwell on distant planets. This journey of exploration starts on the eighth great continent, that we call the Moon.

> *The Earth is the cradle of humanity, but mankind cannot stay in the cradle forever.*
> *—Konstantin Tsiolkovsky*[203]

[k]This vision is even more remarkable when attributed to the philosopher Socrates, who died in 399 B.C.

Figure 18: Earthrise. Credit: Crew of Apollo 8.[204]

VIII. Conclusion

This paper explores the benefits of pursuing manned lunar missions in the near future. While acting as a stepping stone for more complex missions to distant locations such as asteroids and Mars, lunar outposts will serve as the first step in protecting the existence of mankind. In addition, exploration of the Moon will advance technologies and open up new commercial industries, will amplify scientific knowledge in many fields, and will serve to bring nations together in the spirit of global cooperation and peace. Finally, we believe that, inherent in man, there is an instinctive desire compelling us to explore to the farthest reaches of Earth and beyond, and the Moon is next.

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