Return to the Moon

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"Create commercial enterprises based on resources from space that, taken as a whole, support the preservation of the human species, its freedom, and its home planet."

-- Current vision statement of the Interlune-Intermars Initiative, Inc.

The spacesuit and life-support backpack, which made geological fieldwork in space possible, had lightened considerably between the Earth and the Moon. The 210 pounds carried during the last training session in the hot Florida sun had become 35 pounds in the one-sixth Earth's gravity as I went to work in the valley of Taurus-Littrow in December 1972. Movement, although encumbered by the stiffness of the spacesuit, actually became easier that on Earth as the technique of cross-country skiing I learned in Norway could be applied - gliding just above the dusty surface with longer and longer strides until speeds of more than 10 km per second could be sustained. Notetaking by radio transmission was a skill acquired long ago during months of simulated lunar field traverses in relevant geological locales throughout the United States. Specialized sampling and photographic techniques and equipment completed the scientific foundations for the Apollo Program's exploration of the Moon.

Trips to the Moon figured prominently in the history of the world during the latter half of the 20th Century. A return to the Moon in the first decades of the 21st Century may be even more significant. My interest in this possibility stems from having participated in the exploration of the Moon's Taurus-Littrow Valley as the only scientist to go to the Moon, as the Lunar Module Pilot on the last of the Apollo Missions, Apollo 17. This personal opportunity came as a result of President John F. Kennedy's 1963 challenge to Americans, "to go to the Moon and return safely to Earth." Kennedy's inspiration coincided with a remarkable superposition of four social phenomena – public concern about the future, a sufficient base of technology, a catalytic and focusing event, and a leader who recognized a unique opportunity. The coincidence of these phenomena in the America of the 1960s provided the foundation for the success of Apollo, just as it did earlier for Thomas Jefferson's Lewis and Clark Expedition, Theodore Roosevelt's Panama Canal construction, and other critical endeavors in the history of the United States.

It is not clear if just one person decided that a scientist, preferably a geologist, should go to the Moon during Apollo and join those who had served the nation in this capacity during previous explorations. Certainly Eugene M. Shoemaker of the U.S. Geological Survey and George Low, the Apollo Spacecraft Program Manager, played a prominent role in creating an environment in which such an event could occur. My essential part in this history was confined to be selected in 1965 as one of the first six scientist-astronauts out of about 1400 who applied; to succeed in becoming a jet and helicopter pilot in competition with Air Force and Navy students; and to demonstrate that I could be trusted with performing my various roles as a Lunar Module Pilot on the Apollo 17 Mission as well or better than anyone else available. Also involved may have been a demonstration of a willingness to work 16 hour days and seven day weeks as did 450,000 others to meet President Kennedy's challenge and to see that the movement of humans into space begin.

Not all great undertakings are assured of success, however. Apollo 11 succeeded in landing on the Moon on July 20, 1969, because competitive bidding brought the best of industry to the job, conservative engineering established strong margins of performance and safety, and highly flexible but disciplined management kept the ultimate objectives in perspective. Most importantly, nearly 500,000 highly motivated men and women, mostly in their mid-twenties, believed that meeting President Kennedy's challenge was the most important contribution they could make with their lives. Ten years of 16 hour days, seven day weeks, and the inevitable wear and tear on families could not have been sustained without such a belief. No amount of money would have bought us the quality control, attention to detail, teamwork, and spur of the moment innovation that became the hallmarks of Apollo. And most of this Apollo team were in their mid-twenties, just out of the engineering schools of the country, with only the astronauts and senior managers significantly older.

As President Kennedy appears to have anticipated, Apollo's success contributed in profound ways to the successful conclusion of the Cold War. Émigré reports and post-Cold War examination of Soviet records indicate that Apollo created a belief in the minds of the leadership of the Soviet Union that President Ronald Reagan's 1983 Strategic Defense Initiative probably would be successful as well, ultimately leading to a breakup of Soviet communism.

Apollo also established for all human beings a new evolutionary status in the Solar System. As a consequence, young people alive today realistically can think about living in settlements on the Moon and Mars. They can anticipate helping their home planet survive itself as America helped former homelands in Europe and Asia defeat oppression in the 20th Century. All in all, we have had an unprecedented and continuing return on the 1960's investment in a "race to the Moon." Both Americans and Russians can be proud of the results of their competition in that race.

Assistance to the Earth from future settlers of the Moon will come as a direct result of the scientific discoveries of Apollo, echoing earlier events in the history of the United States. The explorations of President Thomas Jefferson's 1803 Louisiana Purchase by Meriwether Lewis and William Clark lay the foundations for the growth of the economy and power of the United States. Theodore Roosevelt's project to construct a canal and lock system across Panama made the United States a naval power on two oceans and produced an explosion in medical, construction, and electrical technology. Similarly, the exploration of the Moon by Apollo astronauts created the Earth's first preeminent spacefaring nation and stimulated rapid advances in most fields of engineering. Additionally, Apollo lay the foundations for future terrestrial energy alternatives to fossil fuels, the growth of a lunar economy, and the settlement of the solar system by humans. In anticipation of such implications, and even before the first lunar landing, Apollo Spacecraft Program Manager George Low and others had introduced lunar science as the second major objective of Apollo. Five other scientists and I were selected as the first scientist astronauts because of that foresight. Plans were made and contracts issued for special equipment, landing site selection, and extended missions. Astronaut training began to emphasize the knowledge and skills necessary to conduct meaningful fieldwork on the Moon in addition to operational mission training.

Once on the Moon, the astronaut-explorers applied their skill systematically at selected locations along traverses planned in detail before each mission. During the three early missions, the explorers walked to each planned location for sampling, observation, and photography while during the last three missions, a Lunar Roving Vehicle was used to greatly expand the area covered. In spite of the planning, and probably because of it, we ran into the unexpected discovery or complication that made concurrent support from a scientific support group on Earth extremely helpful. Thus, as a consequence of lunar exploration by twelve Americans, and the more recent robotic exploration and scientific analysis built on that foundation, we have detailed first and second order understandings of the nature and history of the Moon, the smallest of the terrestrial planets. By extrapolation, we gained vastly improved insights about the history of other terrestrial planets – Earth, Venus, Mars and Mercury. We have scientific visibility into the first one and a half billion years of the geologically clouded history of the Earth, including aspects related to the origin of life, not accessible by any other means.

For example, it is now clear that the origins of the Moon and our home planet were closely related. Not yet certain, however, is whether the Moon's presence around Earth resulted from a giant impact on the Earth or by the Earth's capture of a small planet co-orbiting the sun. After its accretion from the solar nebula about 4.57 billion years ago, an ocean of hot magma existed on the Moon for about 50 million years during which mineral crystallization and density separation in that ocean caused the differentiation of a crust and a mantle. For the next 700 million years, intense bombardment by asteroids and/or comets cratered and pulverized the lunar surface and the surfaces of other terrestrial planets, ending about 3.8 billion years ago. Great surface eruptions of lava then dominated the next billion years, gradually dying out as the Moon cooled. Many other details of lunar history are known, but it may be most interesting to note the match between the appearance of isotopic evidence of life on the water-rich Earth with the end of the great bombardment, both occurring 3.8 billion years ago. The end of the extraordinary impact violence at this point in solar system evolution may have finally permitted simple, replicating life to form at the surface of the Earth from a clay soup rich in water, complex organic molecules, and other necessary components. The same process may have begun on Mars only to be arrested later by the loss of its oceans and atmosphere.

The tie between preparation and planning and scientific debate and understanding is illustrated by my discovery of the Apollo 17 deposit of orange pyroclastic volcanic glasses. Data from these glasses have contributed significantly to the continuing debate over the origin of the Moon. The discovery of orange volcanic glass ("orange soil") in the rim of Shorty Crater and close to its original point of deposition 3.7 billion years ago, subsequent recognition of volcanic glasses as a widespread component of the lunar regolith, and detailed examination of these glasses in terrestrial laboratories established a number of new geochemical constraints on the origin of the Moon. Finding the orange glass came from a convergence of a number of factors. First, one of the primary objectives of the mission to Taurus-Littrow was the search for the cause of dark mantling, possibly pyroclastic (explosive) volcanic deposits in the region. Second, pre-mission consideration of multiple hypotheses for the origin of the dark-halo crater called Shorty included the possibility that it might be a volcanic vent even though all the evidence then available pointed to an impact origin. Finally, my own experience in volcanic provinces on Earth and normal field geologist's instincts to watch one's feet probably were important factors. From the moment of discovery, it was clear that the orange soil would be significant, but how significant was not known until its return to Earth. It took detailed investigations in terrestrial laboratories before the soil's makeup of glass beads and their ramifications slowly became clear. The primary importance of the pyroclastic glasses relative to lunar origin lies in their deep origins and in the composition of the adsorbed volatiles on the surfaces of the small glass beads and devitrified glass beads. The volatiles suggest that the lower mantle (below 550 km) is largely undifferentiated and close to chondritic in many aspects of its composition.

Most importantly, for future inhabitants of Earth and space, we know from the Apollo lunar samples that fusion energy resources (solar wind helium-3, a light isotope of normal helium) exist in the pulverized upper several meters of the Moon's surface. (Fusion energy is produced by combining atoms whereas fission energy is produced by splitting atoms.) These potentially commercial energy resources provide both a long-term alternative to our use of fossil fuels on Earth as well as the basis for future lunar and Martian settlement. Further, byproducts of the extraction of helium-3 from the lunar surface can sustain the future travelers and settlers of deep space with water, oxygen, hydrogen fuel, and food.

I doubt, however, that the United States or any government will initiate or finance a return of humans to the Moon or a human expedition to Mars in the foreseeable future. Governments, particularly that of the United States, have a very pragmatic excuse for turning their financial backs on the potential of a return to the

Moon. I learned during a term as a U.S. Senator that it is very difficult, politically, to commit to the long-term allocation of the required taxpayer-provided funds for space or any other so-called "discretionary" activities. This would be true under any circumstances but is made impossible now by the inability of governments to fund retirement and health security for the elderly and the poor by means other than income transfer from one generation to the next. Income transfer will lead to higher and higher tax rates on the children of the World War II Baby Boom as their parents begin to retire early in the 21st Century. By training and inclination most elected officials work to treat the symptoms of social problems rather than to solve those problems. Few of us in the non-political world can afford this luxury.

The private sector, on the other hand, may find a business rationale for a return to the Moon, based on the economic value in the extraction of lunar helium-3 and its use as a fusion fuel on Earth, providing a future economic and environmental alternative to fossil fuels. This possibility has been studied extensively by my colleagues and me at the University of Wisconsin-Madison since 1985 and continues to appear to be a feasible approach to a return to the Moon and to providing clean terrestrial energy in the future. In addition, byproducts of helium-3 extraction from the pulverized lunar surface soils will include hydrogen, oxygen, and water – valuable materials needed for consumption by humans elsewhere in space. Thus, the next return to the Moon probably will approach work on the lunar surface very pragmatically, with humans in the roles of exploration geologist, mining geologist/engineer, heavy equipment operator/engineer, heavy equipment/robotic maintenance engineer, mine manager, and the like. To be successful, of course, a lunar resource and terrestrial fusion power business must be based on competitive rates of return to investors, innovative management of financial and technical risk, and reasonable regulatory and treaty oversight by government.

The long-term business case for private sector involvement in a return to the Moon most directly relates to terrestrial needs for clean energy. The global demand for energy will likely increase by a factor of eight or more by 2050. This will be due to a combination of needs reflecting the doubling of world population, new energy intensive technologies, demands to avoid the adverse consequences of climate change, and aspirations for improved standards of living in the less-developed world. Lunar helium-3, with a resource base in the titanium-rich basaltic soils of Mare Tranquillitatis of at least 10,000 tonnes, represents one of several potential energy sources to meet this rapidly escalating demand. The results from the 1997-99 Lunar Prospector orbiting neutron spectrometer analyses suggest that helium-3 also may be concentrated at the lunar poles along with solar wind hydrogen. The energy equivalent value of helium-3 delivered to future fusion power plants on Earth would be about $3 billion per tonne relative to $21 per barrel crude oil. The domestic U.S. electrical power market is worth approximately $120 billion, annually. Some 40 tonnes of helium-3 contain enough energy to supply that market's needs for one year. These numbers illustrate the theoretical magnitude of the potential business opportunity in a return to the Moon. In addition, the technology and facilities required for success of a lunar commercial enterprise will make possible and reduce the cost of continued scientific investigations on and from the Moon, space station re-supply, exploration and settlement of Mars, asteroid interception and diversion to prevent impact on the Earth, and many other future space activities.

Mining, extraction, processing, and transportation of helium-3 to Earth, and the use of byproducts in space, requires new innovations in robotic and long-life engineering but no known new engineering concepts (Figure 1). A business enterprise based on lunar resources will be driven by cost considerations to minimize the number of humans required for the extraction of each unit of resource. Humans will be required on the Moon, on the other hand, to reduce the business risk of lunar operations; to prevent costly breakdowns of

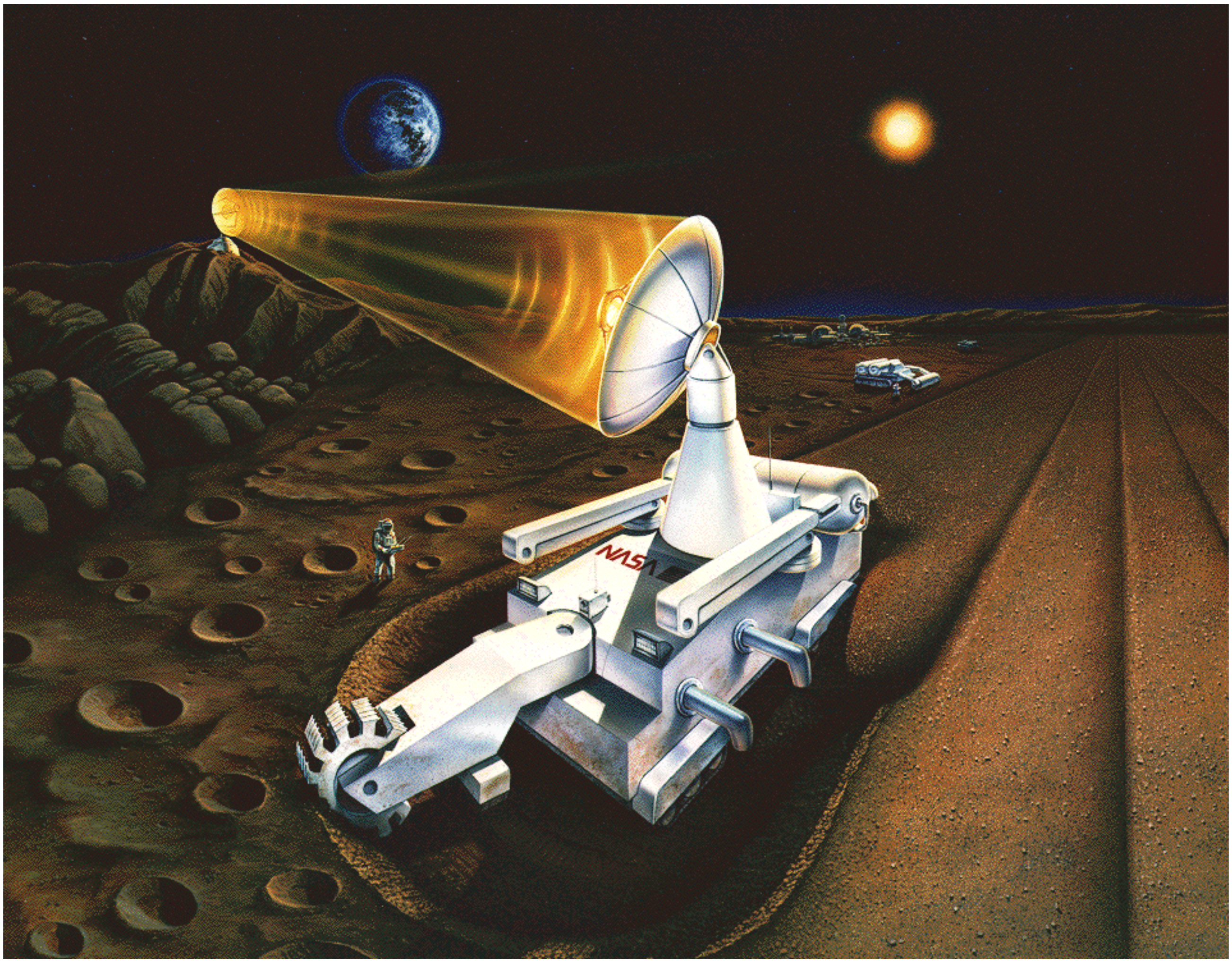

Figure 1. Concept for a mobile mining/processing machine for the extraction of solar wind volatiles, including helium-3, from lunar soils (courtesy of the Fusion Technology Institute, University of Wisconsin-Madison).

semi-robotic mining, processing, and delivery systems; to provide manual backup to robotic or telerobotic operation; and to support other lunar activities in general. The creation of capabilities to support mining operations also will provide the opportunity for renewed scientific exploration at much reduced expense with the cost of capital for launch and basic operations being carried by the business enterprise.

During the early years of operation the number of personnel at a lunar resource extraction settlement will be about six per mining/processing unit plus four support personnel per three mining/processing units. Cost considerations also will drive business to encourage or require personnel to become settlers, provide all medical care and recreation, and provide technical control for most or all operations on the Moon. It will always be important to remember Wallace Stegner's reminder that "a place is not a place until people have lived and died there."

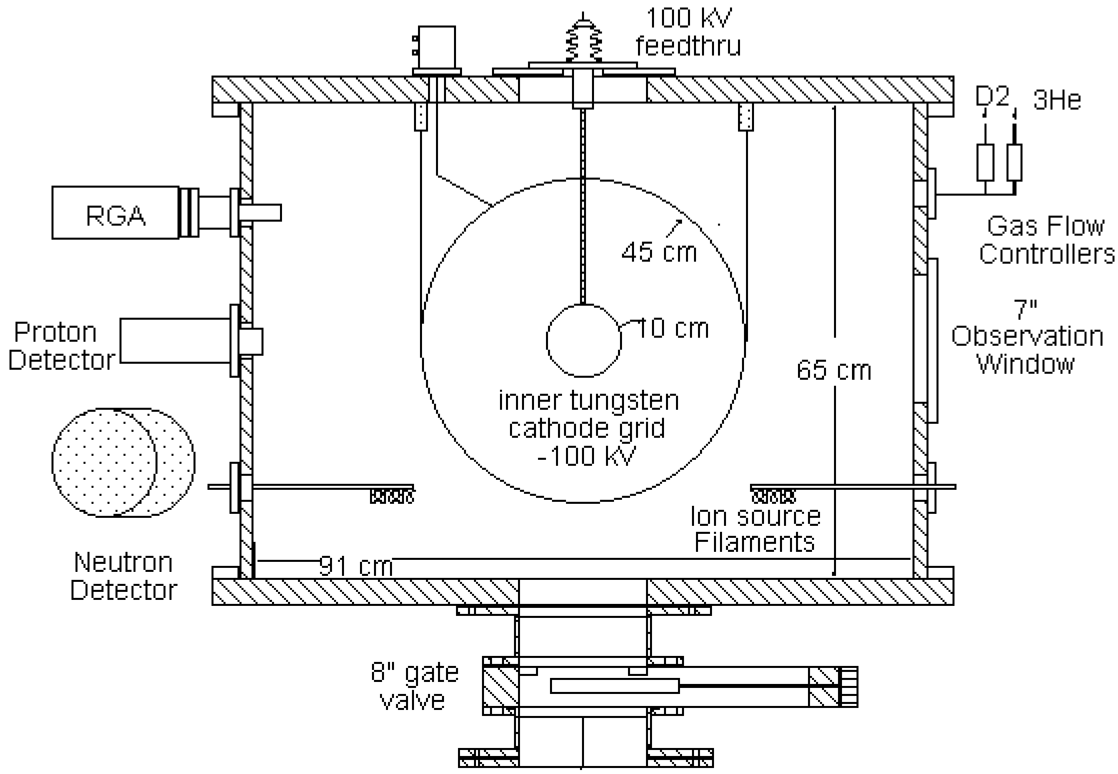

Figure 2. Schematic cross-section through an Inertial Electrostatic Confinement device for laboratory experimentation (courtesy of the Fusion Technology Institute, University of Wisconsin-Madison).

The questions probably will always be asked: “Why humans in space or on the Moon? Wouldn’t robots be better and safer?” Setting aside the inherent desire for human beings to “be there” wherever “there” may be, I know from personal experience that on the Moon, humans contribute to space operations in unique and valuable ways. As with the discovery of the orange soil, they will provide instantaneous observation, interpretation, and assimilation of the environment in which they work and a creative reaction to that environment. Human eyes, experience, judgement, ingenuity, and manipulative capabilities are unique in and of themselves and highly additive in synergistic and spontaneous interaction with instruments and robotic systems. Due to inherent communication delays and the cost of returning samples and providing mission support, the deeper into space human beings desire to go, the more important will become these unique human attributes.

Near-term, the more critical and enabling question is: “Can you cut the cost of access to deep space from the approximately $70,000 per kilogram (including the additional cost of private capital) required by the Apollo Saturn V rocket and by existing heavy lift technology?” Heavy lift launch costs constitute the largest cost uncertainty facing initial business planning; however, many factors, particularly long-term production contracts, promise to lower these costs into the range of $1-2000 per kilogram. Also contributing to a reduction in launch costs will be nearly 40 years engineering experience with heavy lift rockets and a clear focus on a set of business and financial requirements. New technologies that have not been applied to Saturn V level rocket capabilities include lightweight materials, microelectronic and micromechanical devices, imbedded computer controls, new manufacturing approaches, and many others.

Figure 3. Apollo 17 photograph of the crescent Earth rising over the far-side lunar horizon (courtesy of NASA).

Another critical question relates to the technology base for the use of helium-3 as a fusion fuel. Inertial electrostatic confinement (IEC) fusion technology (Figure 2) appears to be the most attractive and least capital intensive approach to terrestrial fusion power plants. Although great amounts of public funds have been spent on fusion research over the last half-century, this research has almost exclusively focused on the technology of non-electrostatic confinement devices. These technologies suffer from numerous disadvantages in their possible application to commercial electrical power plants, including very high capital and operating costs, large minimum operating size, relatively low conversion efficiency through a heat cycle, and radioactive fuel and waste products. In contrast, IEC technology inherently offers the potential for low capital costs, size flexibility, high conversion efficiency through direct conversion of charged particles, and non-radioactive fuel and no radioactive waste. Over the last two decades, steady progress in the advancement of IEC fusion technology has been made by my colleagues at the University of Wisconsin-Madison's Fusion Technology Institute under the guidance of Professor G.L. Kulcinski.

A private enterprise approach to developing lunar helium-3 and terrestrial IEC fusion power would be the most expeditious means of realizing this unique opportunity. In spite of the large, long-term potential return on investment, access to capital markets for a lunar helium-3 and terrestrial fusion power business will require a near-term return on investment, based on early applications of IEC fusion technology. The most obvious such application will be in the low cost, point-of-use production of short half-life medical isotopes.

The international space treaty environment forms an important backdrop to a return to the Moon for its resources. The only space treaty related to the use of space resources to which the United States is a party, is the 1967 “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space”, or Outer Space Treaty. The Outer Space Treaty specifically provides a generally recognized legal framework for such use. The Treaty does not contain specific rules relative to the extraction and use of lunar resources, however, its provisions imply certain guidelines for such activities. Compliance with these guidelines by a legal corporate entity under the laws of the United States would be straightforward. The 1979 Moon Agreement (commonly referred to as the Moon Treaty) has confused the treaty environment somewhat, but that Agreement has not been ratified by major spacefaring nations. If it were so ratified, it would build in a high degree of uncertainty that is antithetical to private commercial activities on the Moon. The Agreement would, in effect, create a moratorium on such activities. The Agreement's mandated international regime would both complicate private commercial efforts and give other countries political control over the permissibility, timing, and management of all U.S. sanctioned commercial activities.

Thus, a return to the Moon inherently has both great potential and great challenges. The 20th Century, however, saw the beginning of the movement of the human species into space, best symbolized by the astronaut's photographs of the crescent Earth rising over the lunar horizon (Figure 3). A return to the Moon to stay early in the 21st Century will be the most logical next step in continuing the migration begun out of Africa hundreds of thousands of years ago and of continuing to realize benefits from such migration to the human race.

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