SCOPE OF MINING ON THE MOON - A CRITICAL APPRAISAL

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ABSTRACT

This paper presents a critical review of mineral resources available on the moon. Samples collected in 1969 by Neil Armstrong during the first lunar landing showed that helium-3 concentrations in lunar soil are at least 13 parts per billion (ppb) by weight. Levels may range from 20 to 30 ppb in undisturbed soils. Quantities as small as 20 ppb may seem too trivial to consider. But at a projected value of $40,000 per ounce, 220 pounds of helium-3 would be worth about $141 million. Because the concentration of helium-3 is extremely low, it would be necessary to process large amounts of rock and soil to isolate the material. Digging a patch of lunar surface roughly three-quarters of a square mile to a depth of about 9 ft. should yield about 220 pounds of helium-3--enough to power a city the size of Dallas or Detroit for a year. Although considerable lunar soil would have to be processed, the mining costs would not be high by terrestrial standards. Automated machines might perform the work. Extracting the isotope would not be particularly difficult. Heating and agitation release gases trapped in the soil. As the vapors are cooled to absolute zero, the various gases present sequentially separate out of the mix. In the final step, special membranes would separate helium-3 from ordinary helium. The total estimated cost for fusion development, rocket development and starting lunar operations would be about $15 billion. The International Thermonuclear Reactor Project, with a current estimated cost of $10 billion for a proof-of-concept reactor, is just a small part of the necessary development of tritium-based fusion and does not include the problems of commercialization and waste disposal. In case of creating helium -3 with nuclear fusion method on the earth, considerable radioactive waste will be generated. However, if helium -3 is extracted from moon, radioactive pollution on earth can be minimized. Thus, emphasis is made in this paper for further exploration for various mineral deposits on moon, and design innovative methods of extraction suitable for the geomining conditions of the moon for eco-friendly mining.

1. INTRODUCTION

In 1985, young engineers at the University of Wisconsin discovered that lunar soil contained significant quantities of a remarkable form of helium. Known as helium-3, it is a lightweight isotope of the familiar gas that fills birthday balloons. Small quantities of helium-3 previously discovered on Earth intrigued the scientific community. The unique atomic structure of helium-3 promised to make it possible to use it as fuel for nuclear fusion, the process that powers the sun, to generate vast amounts of electrical power without creating the troublesome radioactive byproducts produced in conventional nuclear reactors.

Extracting helium-3 from the moon and returning it to Earth would, of course, be difficult, but the potential rewards would be staggering for those who embarked upon this venture. Helium-3 could help the world--from dependence on fossil fuels. That vision seemed impossibly distant during the decades in which manned space exploration languished. Americans and others made repeated trips into Earth orbit, but humanity seemed content to send only robots into the vastness beyond. That changed on Jan. 14, 2004, when President George W. Bush challenged NASA to "explore space and extend a human presence across our solar system."

It was an electrifying call to action for those of us who share the vision of Americans leading humankind into deep space, continuing the ultimate migration that began 42 years ago when President John F. Kennedy first challenged NASA to land on the moon.

Although the president's announcement did not mention it explicitly, his message implied an important role for the private sector in leading human expansion into deep space. In the past, this type of public-private cooperation produced enormous dividends. Recognizing the distinctly American entrepreneurial spirit that drives pioneers, the President's Commission on Implementation of U.S. Space Exploration Policy subsequently recommended that NASA encourage private space-related initiatives. If government efforts lag, private enterprise should take the lead in settling space. We need look only to our past to see how well this could work. In 1862, the federal government supported the building of the transcontinental railroad with land grants. By the end of the 19th century, the private sector came to dominate the infrastructure, introducing improvements in rail transport that laid the foundation for industrial development in the 20th century. In a similar fashion, a cooperative effort in learning how to mine the moon for helium-3 will create the technological infrastructure for our inevitable journeys to Mars and beyond. Fig 1 shows astronaut landing on the moon.

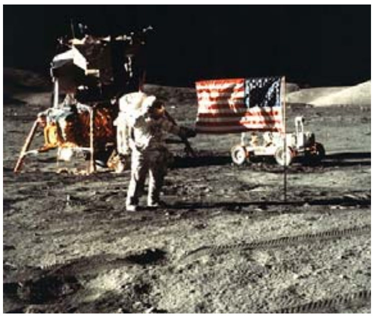

Fig 1: Astronaut landing on the moon.

The Basics of Limitless Power: Albert Einstein's famous E=MC2 equation reflects the enormous energy that can be released by fusing atoms. Hydrogen atoms fusing together to create helium powers the sun. Investigations in three generations of producing electricity from fusion of atoms (Fig 2 and 3) are discussed below:

First Generation: Scientists have duplicated solar fusion on Earth by using two "heavy" hydrogen atoms--deuterium and tritium--which fuse at lower temperatures than ordinary hydrogen. A first-generation deuterium-tritium fusion reactor operated experimentally for 15 years at the Princeton Plasma Physics Laboratory in New Jersey.

Second Generation: While useful for studying fusion, reactors operating with deuterium-tritium fuel are impractical for commercial use. Among other things, the reaction produces large amounts of radiation in the form of neutrons. Substituting helium-3 for tritium significantly reduces neutron production, making it safe to locate fusion plants nearer to where power is needed the most, large cities. Researchers at the University of Wisconsin Fusion Technology Institute in Madison reported having successfully initiated and maintained a fusion reaction using deuterium and helium-3 fuel.

Third Generation: First-generation fusion reactors were never intended to produce power. And, even if they are perfected, they would still produce electricity in much the same way as it is created today. That is, the reactors would function as heat sources. Steam would then be used to spin a massive generator, just as in a coal- or oil-fired plant. Perhaps the most promising idea is to fuel a third-generation reactor solely with helium-3, which can directly yield an electric current--no generator required. As much as 70 percent of the energy in the fuels could be captured and put directly to work.

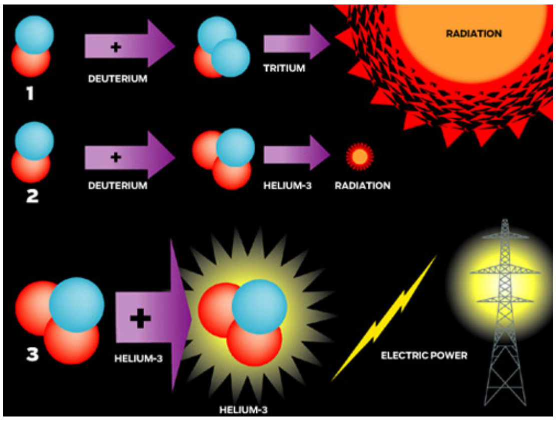

Fig 2: Investigations in three generations for producing electricity from fusion of atoms

2. RESOURCE ON MOON - HELIUM -3

Throughout history, the search for precious resources--from food to minerals to energy--inspired humanity to explore and settle ever-more-remote regions of our planet. Helium -3 could be the resource that makes the settlement of our moon both feasible and desirable. Although quantities sufficient for research exist, no commercial supplies of helium-3 are present on Earth. If they were, we probably would be using them to produce electricity today. The more we learn about building fusion reactors, the more desirable a helium-3-fueled reactor becomes. Researchers have tried several approaches to harnessing the awesome power of hydrogen fusion to generate electricity. The stumbling block is finding a way to achieve the temperatures required to maintain a fusion reaction. All materials known to exist melt at these surface-of-the-sun temperatures. For this reason, the reaction can take place only within a magnetic containment field, a sort of electromagnetic Thermos bottle.

Initially, scientists believed they could achieve fusion using deuterium, an isotope of hydrogen found in seawater. They soon discovered that sustaining the temperatures and pressures needed to maintain the so-called deuterium-deuterium fusion reaction for days on end exceeded the limits of the magnetic containment technology. Substituting helium-3 for tritium allows the use of electrostatic confinement, rather than needing magnets, and greatly reduces the complexity of fusion reactors as well as eliminates the production of high-level radioactive waste. These differences will make fusion a practical energy option for the first time.
It is not a lack of engineering skill that prevents us from using helium-3 to meet our energy needs, but a lack of the isotope itself. Vast quantities of helium originate in the sun, a small part of which is helium-3, rather than the more common helium-4. Both types of helium are transformed as they travel toward Earth as part of the solar wind. The precious isotope never arrives because Earth's magnetic field pushes it away. **Fortunately, the conditions that make helium-3 rare on Earth are absent on the moon, where it has accumulated on the surface and been mixed with the debris layer of dust and rock, or regolith, by constant meteor strikes.** An aggressive program to mine helium-3 from the surface of the moon would not only represent an economically practical justification for permanent human settlements; it could yield enormous benefits back on Earth.

Budget cuts, a public bored with space and fear of losing a crew--*Apollo 13* was still a vivid memory--turned Apollo 17 into the last moon mission of the 20th century. NASA decided to get the most scientific data possible from its last lunar excursion and made a crew change: Harrison H. Schmitt became the first and only fully trained geologist to explore the moon. Schmitt was a natural choice. With a doctorate from

Harvard University, he was already on the staff of the U.S. Geological Survey's astrogeology branch in Flagstaff, Ariz. His job included training astronauts during simulated lunar field trips. There was only one hole in his résumé. Schmitt had never learned to fly. In 18 months he earned his wings, and became a jet plane and lunar landing module pilot.

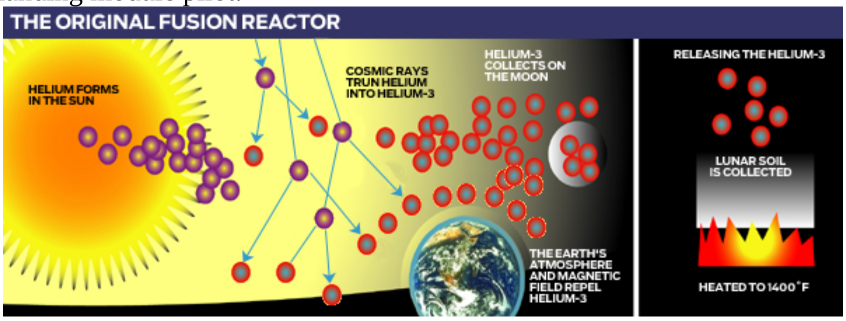

Fig 3: Fusion reactor

On Dec. 11, 1972, he and Eugene Cernan landed in the moon's Taurus-Littrow Valley. On the first of three moonwalks, Schmitt's scientific knowledge became evident. So did his enthusiasm. His periodic falls stopped hearts at Mission Control, which feared he would rip his spacesuit and die instantly. Four years after returning with 244 pounds of moon rocks, Schmitt was elected U.S. senator from New Mexico. Now chairman of Albuquerque-based Interlune-Intermars Initiative, he is a leading advocate for commercializing the moon.--*S.C.*

3.PROSPECTS OF MINING ON MOON

Samples collected in 1969 by Neil Armstrong during the first lunar landing showed that helium-3 concentrations in lunar soil are at least 13 parts per billion (ppb) by weight. Levels may range from 20 to 30 ppb in undisturbed soils. Quantities as small as 20 ppb may seem too trivial to consider. But at a projected value of $40,000 per ounce, 220 pounds of helium-3 would be worth about $141 million. Because the concentration of helium-3 is extremely low, it would be necessary to process large amounts of rock and soil to isolate the material. Digging a patch of lunar surface roughly three-quarters of a square mile to a depth of about 9 ft. should yield about 220 pounds of helium-3--enough to power a city the size of Dallas or Detroit for a year. Although considerable lunar soil would have to be processed, the mining costs would not be high by terrestrial standards. Automated machines might perform the work. Extracting the isotope would not be particularly difficult. Heating and agitation release gases trapped in the soil. As the vapors are cooled to absolute zero, the various gases present sequentially separate out of the mix. In the final step, special membranes would separate helium-3 from ordinary helium. The total estimated cost for fusion development, rocket development and starting lunar operations would be about $15 billion. The International Thermonuclear Reactor Project, with a current estimated cost of $10 billion for a proof-of-concept reactor, is just a small part of the necessary development of tritium-based fusion and does not include the problems of commercialization and waste disposal.

The second-generation approach to controlled fusion power involves combining deuterium and helium-3. This reaction produces a high-energy proton (positively charged hydrogen ion) and a helium-4 ion (alpha particle). The most important potential advantage of this fusion reaction for power production as well as other applications lies in its compatibility with the use of electrostatic fields to control fuel ions and the fusion protons. Protons, as positively charged particles, can be converted directly into electricity, through use of solid-state conversion materials as well as other techniques. Potential conversion efficiencies of 70 percent may be possible, as there is no need to convert proton energy to heat in order to drive turbine-powered generators. Fusion power plants operating on deuterium and helium-3 would offer lower capital and operating costs than their competitors due to less technical complexity, higher conversion efficiency, smaller size, the absence of radioactive fuel, no air or water pollution, and only low-level radioactive waste disposal requirements. Recent estimates suggest that about $6 billion in investment capital will be required to develop and construct the first helium-3 fusion power plant. Financial breakeven at today's wholesale electricity prices (5 cents per kilowatt-hour) would occur after five 1000-megawatt plants were on line, replacing old conventional plants or meeting new demand.

While lunar rare earth elements may or may not be up for grabs, there's still another resource on the moon of high-value. For rare earths, they are called rare for their low abundance, not economic value. However, some do have practical use in manufacturing, as in superconducting magnets. According to a planetary scientist and leading advocate for exploring the moon at the Lunar and Planetary Institute in Houston, the moon-situated rare earth elements are in very low abundance, except in the KREEP terrain of the western near side.

The possibility of mining lunar thorium can also be considered, which is not a rare earth, strictly speaking, but associated with them to fuel nuclear reactors for power generation at a lunar base, which is quite a distant prospect. The real strategic lunar commodity is water. It's useful for life support, energy storage, and propellant. It can be extracted on the moon and exported to cislunar space to create a permanent transportation system. A strategic question to be considered is “on the 20- to 50-year timeframe, are there valuable or strategic resources on the moon?”

4. CHALLENGE TO MINING THE MOON - NEW SPACECRAFT

Perhaps the most daunting challenge to mining the moon is designing the spacecraft to carry the hardware and crew to the lunar surface. The Apollo *Saturn V* spacecraft remains the benchmark for a reliable, heavy-lift moon rocket. Capable of lifting 50 tons to the moon, *Saturn V*'s remain the largest spacecraft ever used. In the 40 years since the spacecraft's development, vast improvements in spacecraft technology have occurred. For an investment of about $5 billion it should be possible to develop a modernized Saturn capable of delivering 100-ton payloads to the lunar surface for less than $1500 per pound. Returning to the moon would be a worthwhile pursuit even if obtaining helium-3 were the only goal. But over time the pioneering venture would pay more valuable dividends. Settlements established for helium-3 mining would branch out into other activities that support space exploration. Even with the next generation of Saturns, it will not be economical to lift the massive quantities of oxygen, water and structural materials needed to create permanent human settlements in space. We must acquire the technical skills to extract these vital materials from locally available resources. Mining the moon for helium-3 would offer a unique opportunity to acquire those resources as byproducts. Other opportunities might be possible through the sale of low-cost access to space. These additional, launch-related businesses will include providing services for government-funded lunar and planetary exploration, astronomical observatories, national defense, and long-term, on-call protection from the impacts of asteroids and comets. Space and lunar tourism also will be enabled by the existence of low-cost, highly reliable rockets.

With such tremendous business potential, the entrepreneurial private sector should support a return to the moon, this time to stay. For an investment of less than $15 billion--about the same as was required for the 1970s Trans Alaska Pipeline--private enterprise could make permanent habitation on the moon the next chapter in human history.

5. EXPLORATION OF THE SOLAR SYSTEM - LIVING OFF THE LAND

Exploration of the solar system will be fueled by materials found scattered across asteroids, moons and planets. The discovery of a helium isotope, helium-3, on the moon has given scientists ideas on how to produce electricity far more efficiently than with hydrocarbons or current nuclear plants. The large amounts of energy would come without danger of releasing radioactive substances into the atmosphere.

Mining the lunar surface would not be cheap; the investment would be comparable to building a major transcontinental pipeline.

6. MINERALS ON THE MOON

The moon could become a wellspring of essential resources ? but at what quality, quantity and outlay to extract? there are local concentrations of rare earth elements (REE) on the moon, and it was found from the returned samples that investigators have not sampled these REE concentrations directly, but can readily detect them along a mixing line with many of the samples investigators do have. The NASA Moon Mineralogy Mapper, known as M3, was carried on Indias Chandrayaan-1 lunar-orbiting spacecraft. That probe was lofted by the Indian Space Research Organization in October 2008 and operated around the moon until late August 2009.

Among other findings, the M3 gear found a whole new range of processes for mineral concentrations on the moon, which was unappreciated until now. The M3 experiment detected a new lunar rock; a unique mixture of plain-old plagioclase, plentiful in the Earths crust and the moons highlands and pink spinel, an especially beautiful arrangement of magnesium, aluminum and oxygen that, in its purest forms, is prized as a gemstone here on Earth.

Lunar scientists have a good idea how lunar rare earth elements became concentrated. It occurred as part of the moon's magma ocean differentiation sequence. But it is now also recognized that early events disrupted and substantially reorganized that process to be deciphered.

With the recent, but limited, new data for the moon from the international fleet of lunar orbiters with remote sensing instruments, from Europe, Japan, China, India and now the United States, investigators are beginning to see direct evidence for the activity of geologic processes that separate and concentrate different minerals.

On the moon, these areas and outcrops are local and small. Exposure is largely dependent on using impact craters as probes to the interior.Current data are only sufficient to indicate the presence of some concentrations of minerals, but are inadequate to survey and map their character and distribution. KREEP is an acronym based on element symbols for the geochemical component in lunar rocks rich in potassium (K), rare-earth elements (REE), phosphorus (P), thorium, and other incompatible elements. These elements are not incorporated into common rock-forming minerals during magma crystallization. Hence, they become enriched in the residual magma and in the rocks that finally do form from it. This is especially so on the moon.

One popular model for the moons formation is that it solidified from a global magma ocean formed from material that aggregated after the young Earth impacted a Mars-sized planet. KREEP is exposed on the lunar surface in certain areas, Gertsch said. Although rare earth elements are not themselves presently detectable by remote instruments, spotting thorium sharpens the ability to spot associated rare-earth elements on the moon's surface due to similar geochemical properties that caused them to crystallize under the same conditions.

However, separating rare earth elements from each other is difficult, because there are few properties where they differ significantly enough to permit efficient sorting of ore particlesat least by standard methods. Rare earth elements do sometimes occur in the ores of other metals. Presumably REE mixtures could be produced on the moon and shipped to Earth for more specific separation. Neither potential mining methods nor the economics of this particular approach have been studied, to my knowledge.

7. EXPLORATION AND BENIFICIATION

It is understood that the moon is rife with rare earth elements. The economies of production hold sway here. Investigators feel that the presence of rare earth elements on the moon can only be truly determined by a dedicated lunar exploration program. That would entail not just orbital sensing techniques, but actual drill cores and sampling in a fashion similar to standard mining and mineral exploration practices here on Earth.

This will only provide gradation data **--** but settle the issue of valuable rare elements on the moon, which can then be used to determine expected returned value and information on the viability of extraction of any particular element. Another issue is not about just digging them up, but rather the entire process of finding and refining. It seems that there is significant quantity of REE's in North America, just not profitable to refine them ... yet. What value is the strategic element in this? Can one put a price on this? If so, it may be economically viable to explore the moon and extract the REEs. In the end, the investigators said, the whole premise revolves on a cost per pound at the user's front door. "A very tough problem and well suited to a mining economist," he concluded.

8. COST OF STRIP-MINING THE MOON

According to some investigators, moon mining costs US$25,000 per kilo to lift things into space on a shuttle. Thus, whatever is mined in space in the future, it will have to be in high-enough demand to subsidise the cost of launching it. This is especially true for prospecting missions beyond the Moon. A mission to retrieve Helium-3 from Jupiter’s atmosphere, for example, would take ten years, and businesses will likely be reluctant to wait a decade for a return on such a pricy investment, says Genge.

Another potential lunar resource – water – could fuel these future missions into deep space. Orbital scans suggest there are at least a billion tonnes of water frozen on the Moon after impacting in craters of the Moon’s surface – usually in the darker areas where temperatures can be as low as 35 degrees Kelvin. Texas-based Shackleton Energy Company has already begun operations aimed at mining the Moon within the next few years. The company’s plans for mining and refining operations would involve melting the ice and purifying the water, converting the water into gaseous hydrogen and oxygen, and then condensing the gases into liquid hydrogen, liquid oxygen and hydrogen peroxide, all potential rocket fuels. The water extracted would be used almost exclusively as rocket fuel to power operations both within Low Earth Orbit (LEO) – such as space tourism and the removal of space-debris – on the Moon, and further out into space. Some enterprises are a for-profit business enterprise moving forward, and so we are only going there really for one reason and that is to mine, prospect mine and harvest water for rocket propellant production.

9. MINERAL RESOURCES ON OTHER PLANETS/ASTEROIDS

Mineral resources on other planets including Mars and asteroids are discussed below:

9.1 Mars

Studies conducted by NASA and others have determined that water, rocket propellant and chemicals needed to sustain a human outpost could be manufactured from Martian soil and ice caps (right). Future astronauts might set up production plants that expand as others arrive. Eventually, the Mars base could become a resupply base.

9.2 Asteroids

Scientists believe these leftovers of the solar system's formation, floating between the orbits of Jupiter and Mars, may contain rare elements and water. Mining these rocks, some as big as mountains, will be neither easy nor cheap. Using technologies previously developed to extract precious materials from the moon or

Mars could make asteroids an attractive target, especially for a permanent human colony on the red planet. Astronauts would first practice rendezvous with asteroids. Then, after studying them, crews would return with mining equipment. Excavated ore could be trucked to a Martian outpost.

9.3 Titan

As early as next year, we may learn whether Saturn's largest moon, Titan, preserves organic molecules similar to those believed to exist on primeval Earth. The Cassini-Huygens spacecraft is designed to determine whether the atmosphere of Titan indeed contains ammonia and hydrocarbons such as ethane and methane. All these chemicals contain a common element: hydrogen. Extracting this gas in a minus 400°F environment could be easier than on Earth since it would be already liquefied and ready to be used as the most powerful chemical rocket fuel. With organic chemicals as ingredients, a limitless array of synthetic materials could be manufactured.

10. CONCLUSIONS

Further exploration and beneficiation of lunar mineral resources can be conducted on priority basis for meeting the demand of electricity in the forthcoming generations. A group of mining engineers, astronauts, geologists etc in the international level may be formed for the purpose. Digging a patch of lunar surface roughly three-quarters of a square mile to a depth of about 9 ft. should yield about 220 pounds of helium-3--enough to power a city the size of Dallas or Detroit for a year. Although considerable lunar soil would have to be processed, the mining costs would not be high by terrestrial standards. Automated machines might perform the work. The International Thermonuclear Reactor Project, with a current estimated cost of $10 billion for a proof-of-concept reactor, is just a small part of the necessary development of tritium-based fusion and does not include the problems of commercialization and waste disposal. In case of creating helium -3 with nuclear fusion method on the earth, considerable radioactive waste will be generated. However, if helium -3 is extracted from moon, radioactive pollution on earth can be minimized. Thus, emphasis is made in this paper for further exploration for various mineral deposits on moon, and design innovative methods of extraction suitable for the geomining conditions of the moon for eco-friendly mining.
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