Mining The Moon

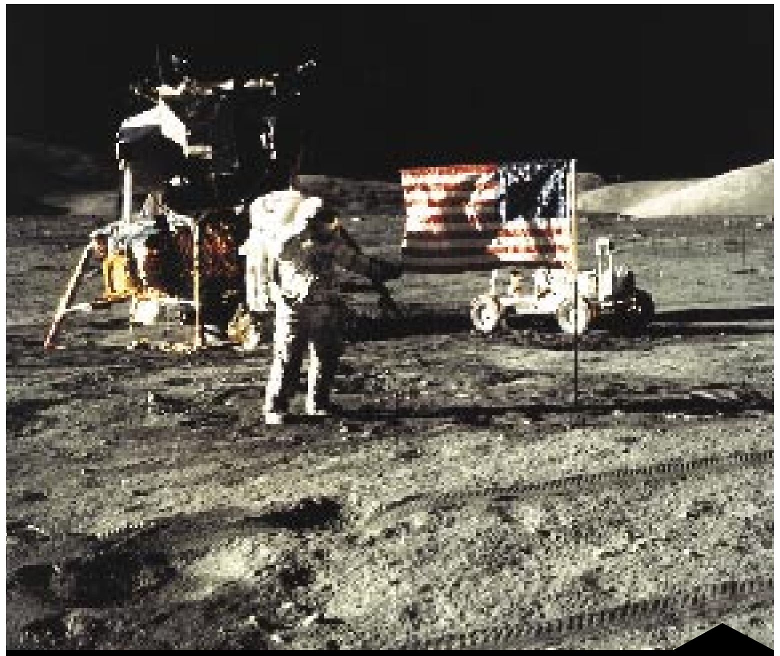
An Apollo astronaut argues that with its vast stores of nonpolluting nuclear fuel, our lunar neighbor holds the key to Earth's future.

BY **HARRISON H. SCHMITT**
ILLUSTRATION BY **PAUL DIMARE**

FUTURE MINERS: Robotic equipment would scrape and refine lunar soil. Helium-3 would be sent to Earth aboard a future space shuttle or perhaps be shot from an electric rail gun.

Apollo 17 **astronaut Harrison Schmitt left the moon 32 years ago with 244 pounds of rocks and an abiding desire to see humankind continue its exploration of space. Now, in an exclusive essay for POPULAR MECHANICS, Schmitt explains why the time is right for America to return.**

A sample of soil from the rim of Camelot crater slid from my scoop into a Teflon bag to begin its trip to Earth with the crew of *Apollo 17*. Little did I know at the time, on Dec. 13, 1972, that sample 75501, along with samples from *Apollo 11* and other missions, would provide the best reason to return to the moon in the 21st century.



HOT PROPERTY: America's last mission to the moon brought back evidence of large amounts of helium-3, a potential energy source.

That realization would come 13 years later. 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 free the United States—and the world—from dependence on fossil fuels.

That vision seemed impossibly distant during the decades in which manned space exploration languished. Yes, 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. We can do so again. If Bush's initiative is sustained by Congress and future presidents, American leadership can take us back to the moon, then to Mars and, ultimately, beyond.

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. I believe in going a step further. I believe that 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.

"Learning how to mine the moon for helium-3 will create the technological infrastructure for our inevitable journeys to Mars and beyond."

PHOTO BY NASA

A REASON TO RETURN

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. I believe that 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.

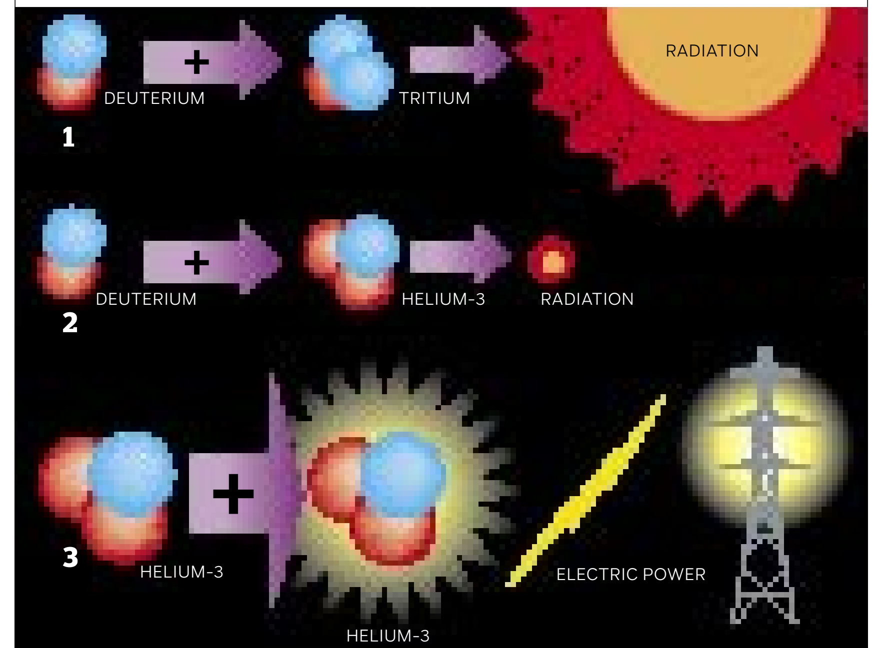
Initially, scientists believed they could achieve fusion using deuterium, an isotope of hydrogen found in seawater. They soon discovered that sustaining the temperatures and pressures needed to maintain the so-called deuterium-deuterium fusion reaction for days on end exceeded the limits of the magnetic 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

ILLUSTRATION BY JANA BRENNING

THREE FACES OF FUSION

THE BASICS OF LIMITLESS POWER: Albert Einstein's famous $E=MC^2$ equation reflects the enormous energy that can be released by fusing atoms. Hydrogen atoms fusing together to create helium powers the sun.

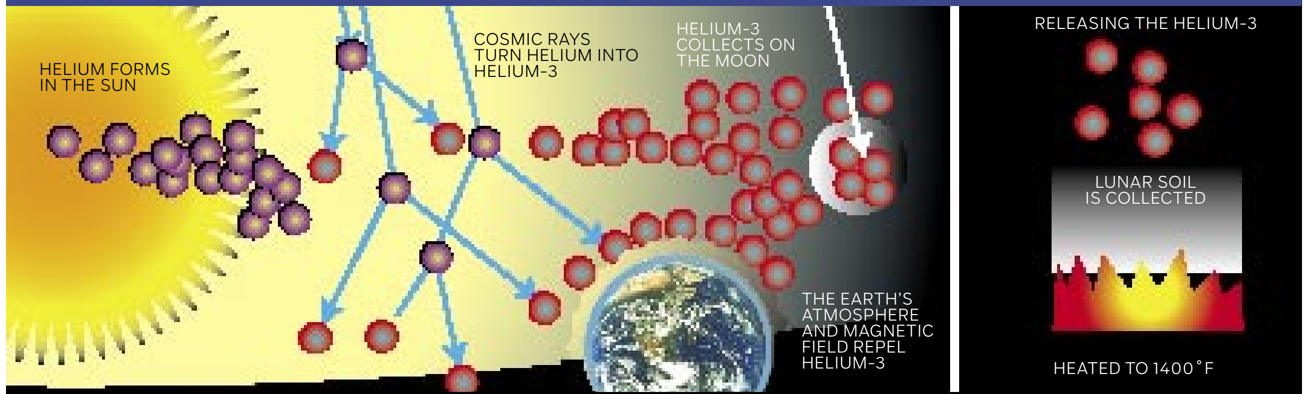


1. FIRST GENERATION: Scientists have duplicated solar fusion on Earth by using two "heavy" hydrogen atoms—deuterium and tritium—which fuse at lower temperatures than ordinary hydrogen. A first-generation deuterium-tritium fusion reactor operated experimentally for 15 years at the Princeton Plasma Physics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

2. 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. This summer, 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.

3. 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. *—Stefano Coledan*

THE ORIGINAL FUSION REACTOR



1. Helium is created in the sun. In space, helium is struck by cosmic rays. Cosmic rays knock out neutrons from helium, turning it into helium-3. Stray neutrons strike other helium atoms, creating more helium-3. 2. Diverted by Earth's magnetic field, helium-3 collects on the moon. 3. Heating rock and soil releases helium and helium-3.

ILLUSTRATION BY JANA BRENNING

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. And there it waits for the taking.

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.

LUNAR MINING

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.

For more science features check out the PM.Zone Web site
POPULARMECHANICS.COM/SCIENCE

Although considerable lunar soil would have to be processed, the mining costs would not be high by terrestrial standards. Automated machines, perhaps like those shown in the illustrations on pages 56 and 57, 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.

"A new, modernized Saturn rocket should be capable of launching 100-ton payloads to the moon."

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.

LUNAR GEM: Rocks brought back to Earth contain traces of helium-3.

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. **PM**

A GEOLOGIST GOES TO THE MOON

PHOTO BY NASA

TRAINED EYE: Geologist Schmitt knew where to find the best rocks.

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. 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.*

Living Off The Land

Exploration of the solar system will be fueled by materials found scattered across asteroids, moons and planets.

Pluto
Neptune
Uranus
Saturn
Titan
Jupiter
Mars
Asteroid belt
Earth
Moon
Venus
Mercury
Sun
Solar flare generating solar wind

ILLUSTRATION BY PAT RAWLINGS/SAIC (SOLAR SYSTEM). INSETS BY NASA

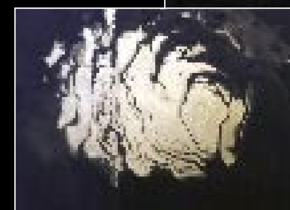
Moon

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.

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.

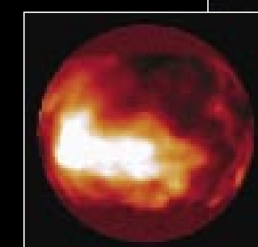


Asteroids

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.

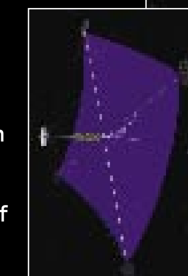
Titan

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.



Space Sails

Earthlings first learned about the existence of the solar wind 35 years ago when *Apollo 11* astronauts Neil Armstrong and Buzz Aldrin deployed a silver-colored sheet on the moon. Scientists wanted to intercept particles coming from the sun.



Taking advantage of this natural source of energy made perfect sense to some within the space community. A lightweight sail (above) could be folded and launched into space. Once in the vacuum of space, the frame attached to a spacecraft would deploy and the square-mile sail could push a spacecraft through interplanetary space faster than conventional propulsion systems, and reach the outer planets in one-fourth the time spacecraft currently take. —S.C.