Lunar Resources

When the astronauts are living and working on the Moon, they will not be able to visit a local hardware or grocery story to get nails and lumber or peanut butter and milk. Everything they need must be shipped from Earth — at a cost of $10,000 per pound — or extracted from the materials available on the Moon. "Everything" includes propellant, power sources, construction materials, food, water, and even air.

The Moon has materials that can support a colony, and these will need to be used efficiently to make human habitation of the Moon sustainable. Once the locations and quantities of potential resources are assessed, the materials will need to be gathered and processed, and manufacturing will be necessary to transform them into usable products.

Water Ice, Maybe. Hydrogen, Yes!

Because the Moon is tilted only slightly on its axis, deep craters at the lunar poles stay in permanent shadow. These are the cold-storage pits of the lunar surface. They are cold enough to trap volatiles — elements that evaporate readily at standard temperature and pressure. Comets striking the surface of the Moon may have delivered water ice that became trapped in the permanently shadowed craters.

Radar data collected by the Clementine spacecraft suggest that water ice, perhaps mixed with regolith, exists at the lunar south pole. Spectrometers onboard the Lunar Prospector detected hydrogen — one component of water — at the lunar poles. Based on the presence and distribution of the hydrogen, scientists hypothesize the presence of extensive water ice at the poles.

Several spacecraft will provide more definitive data about the presence of water ice. NASA's Lunar Reconnaissance Orbiter (LRO) and India's Chandrayaan-1 spacecraft carry radar instruments to map the extent and distribution of materials at the poles in far greater detail than previous missions. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission will help confirm the presence of water ice by impacting the lunar surface in a permanently shadowed crater. The resulting plume will be analyzed for water ice and vapor and other materials. If there is ice at the lunar poles, there are still many questions about how it got there, its composition, how fast it accumulates, and how much regolith is mixed with it.

The presence of water will reduce the cost of transporting this critical resource to the Moon. Beyond the need for drinking water, it can be separated into its two components — hydrogen and oxygen — and used to make propellant for spaceflight. The oxygen can also be used for the production of breathable air. If, however, the hydrogen in the polar regions is not contained in water ice, but accumulated from particles emplaced by solar wind, it is still a vital source of potential energy — although only part of the propellant equation!

Regolith Revisited

Oxygen, critical to future lunar outposts for fuel and breathable air, makes up about 45% of the lunar regolith. It can be extracted from regolith and rock minerals such as ilmenite through a variety of processes that break the chemical bonds. Breaking down ilmenite also produces titanium, a lightweight metal that is as strong as steel and that can withstand extreme temperature fluctuations, making it ideal for lunar structures.

Regolith also has valuable sheltering properties. It can be used to cover lunar structures, helping to regulate temperatures inside and offering protection from incoming cosmic and solar radiation. When regolith is heated, its tiny particles fuse together; future outposts may use fused regolith to create roads or make bricks for buildings.

Lunar Resources continued on next panel

Got Sun?

Energy can be collected by arrays of solar panels and stored during the lunar day, typically 14 Earth days long, and used during the lunar night to provide electricity for the outpost, life support systems, rovers, and other equipment. Sunlight is less direct at the poles, but available for more than 70% of the time on raised surfaces. Future lunar missions, like LRO, will confirm the duration of light. Solar panels placed on crater rims would capture solar energy. The key is figuring out how to store this energy. One possibility is rechargeable batteries. Another is regenerative fuel cells, "batteries" that generate power by combining hydrogen and oxygen. In regenerative fuel cells, all the materials are contained within the cell — there is no need to add resources. During the lunar day, solar power would be used to support the outpost and to split water into oxygen and hydrogen in the fuel cell. At night, the hydrogen and oxygen would be recombined in the fuel cell to generate electricity.

Other Energy Sources

Incoming solar particles, including hydrogen, helium, and small amounts of other elements, have gradually built up in the lunar regolith over billions of years. One of these, helium-3, is of particular interest because it undergoes fusion reactions, and thus has potential as an energy source for the Moon (and possibly for Earth). While the concentrations of helium-3 are low, only small amounts are needed. Some estimates suggest that mining an area on the Moon a little smaller than the city of New Orleans (about 170 square miles or 440 square kilometers) to a depth of 10 feet (3 meters) would meet the energy needs of the United States for one year. At this point in time, converting helium-3 to a viable energy source requires further advances in technology.

What's for Dinner?

With time, lunar explorers will grow their own vegetables. The lack of an atmosphere and the nutrient-poor regolith present challenges. However, scientists are designing enclosures where plants are cultivated hydroponically — in liquid nutrient solutions. Carbon dioxide, a product of human respiration, can be captured and provided to the plant enclosures. The oxygen that the plants release will help create breathable air for the astronauts.

Reduce, Reuse, Recycle

Fundamental to building and sustaining an outpost on the Moon is ensuring that all resources are used efficiently! Transporting materials to the Moon is costly and minimizing waste is essential. Habitat modules, transportation vehicles, and other equipment will be designed so that parts can be interchanged, reducing the need for a large inventory of different parts. Water in the breath exhaled by astronauts, and even from urine, will be collected, sanitized, and reused to support the outpost. New technologies, such as regenerative fuel cells and advanced solar panels, will minimize the consumption of resources and creation of waste byproducts.

Picture It

Robotic missions transport solar panels, small habitats, fuel cells, and other equipment to the Moon. Advanced robots assemble the components, initiate energy collection, and begin surface operations including excavation of lunar materials for water. Humans follow and complete the basic outpost design, ensuring safe living and working modules. Food, water, and air initially are brought from Earth; eventually, these are produced on the Moon, in part from lunar resources. Engineers, mechanics, technicians, and others maintain the outpost, ensuring that life support systems and other equipment function properly. The habitat grows as more activities get underway, including refining raw materials and manufacturing buildings and equipment components. Humans and robots work together in near- and far-ranging expeditions to establish remote instrument stations and to collect data and samples for scientific and resource analysis. Eventually, more people with different skills support the outpost operations, including base managers, medical and laboratory technicians, cooks, and others. What will your role be?