



WORKING ON THE MOON

28 – Lunar Resources

SUMMARY

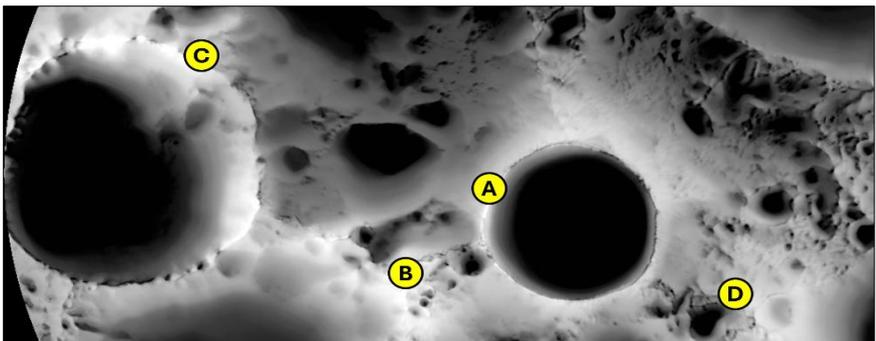
The Moon has some unique resources worth noting. At the top of the list are the so-called polar Peaks of Eternal Light (PELs) and the permanently shadowed regions (PSRs) nearby containing substantial quantities of volatiles. A small percentage of the lunar highland is unoxidized metals. Of particular interest are the results from NASA's 2009 LCROSS mission showing high concentrations of water and substantial amounts of carbon and nitrogen-containing chemicals. Total water could supply a water recycling settlement of a million people for 1,600 years!

The great advantage for planetary destinations is that they have resources readily available unlike free space. As you will see, the Moon has more than enough resources to support not only an initial base but a very large settlement for a very long time.

THE PEAKS OF ETERNAL LIGHT

All the processes involved with establishing an initial permanent base require sufficient power. Fortunately, the poles of the Moon have a particularly favorable power situation.

As the Earth orbits around the sun, it does so with a 23-degree tilt. This is nice in that it gives us the four seasons. Also, as a result, the Earth's poles are exposed to continuous sunlight in the summer and then continuous darkness in the winter.



Four Peaks of Eternal Light on the lunar south pole.

But the Moon is different. It has almost no tilt compared to its orbit around the sun. In fact, the tilt of its axis is only 1.5 degrees. Not only does this mean that it essentially has no seasons but more importantly, there are certain depressed areas including craters where sunlight hit the rims nearly constantly but never hits their floors. As a result, there is the fortuitous situation where locations where solar power can be collected nearly continuously which are relatively close to permanently shadowed dirt where scientists have long speculated that ice may exist over geologic time scales.

Now, some will point out that there are no actual “Peaks of Eternal Light” (PELs) on the Moon. Because of the slight tilt, there are no specific locations that are sunlit 100% of the lunar year. But one of those peaks are sunlit between 87 - 92% of the time on average (ridge between Shackleton and de Gerlache craters). This means that that point has darkness lasting only a few tens of hours. And with solar drapes measuring between 30 and 60 meters in height, the time in sunlight would be increased yet more. That much solar power at one location would still be rather useful.

The use of the lunar pole’s solar power will benefit not only any settlements at the poles but will benefit the entire Moon. This is because, the high-power activities (electrolysis, metallurgy, and growing food) would be preferentially done at these locations and then the product of that production could be shipped from the poles to any other part of the Moon using electric, automated, cargo vehicles with less than a three-day drive.

LUNAR VOLATILES

The LCROSS Mission

Over the years, scientific speculation has led to several craft with a number of instruments attempting to see if water exists on the Moon near the poles. The results were mixed but generally encouraging. Unfortunately, there was always some alternate explanation for the results. So, whereas there was evidence that water ice may exist on the Moon it was never definitive.

Then in 2009, NASA, with the principal investigator, Anthony Colaprete, conducted a rather remarkable study. They were able to add their LCROSS experiment onto an already planned mission which delivered the high-resolution Lunar Reconnaissance Orbiter (LRO) to lunar

orbit. The researchers were able to include a shepherding craft and direct the rocket's Centaur upper stage to descend to the Moon at high speed and crash into Cabeus Crater in the south polar region where suspected ice concentrations were particularly high. The impact kicked up dirt from the floor of Cabeus Crater into the sunlight. The trailing shepherding craft was able to spectroscopically image the resulting ejecta. The results were remarkable.



Screenshots from an LCROSS Missions video. Credit NASA.

It was found that 5.7% by weight of the ejecta kicked up was water ice. That is one part per 18. Compared to the bone-dry areas of the Moon towards the equator, this is an extremely high concentration of water.

But it was not only water that was found. The fingerprints of carbon, nitrogen, and sulfur-containing chemicals were found also. Here's the breakdown of those.

Compared to Water:

- 100% - Water
- 16.75% - H₂S
- 6.03% - NH₃
- 3.19% - SO₂
- 2.17% - CO₂
- 1.55% - CH₃OH
- 0.65% - CH₄
- 0.03% - OH

To help with the comprehension of what these numbers mean, I have constructed a set of boxes that show the relative sizes of the lunar regolith and various chemicals discovered by LCROSS. Below is what a cubic meter of icy regolith would look like if the components were broken down into separate cubes. The density of the chemicals in their liquid form is much less than that of the dry regolith. As a result, their volumes appear larger than their weights.

No longer can critics of the Moon claim that there is no carbon or nitrogen on the Moon. There are unmistakable spectroscopic fingerprints of nitrogen-containing ammonia and carbon-containing molecules such as ethylene, methanol, carbon monoxide, and methane. And their relative concentrations mean that any ice-harvesting operation to produce propellant quantities of water would give abundant carbon and nitrogen especially for bases and settlements which recycle those chemicals.

Of equal importance is the total quantity of these volatiles. Take water for example. The best data indicate that there is at least 600 million

metric tons of water collectively at both lunar poles. If a settlement of a million people were to recycle their water and so have reduced need to replenish those losses, that city would have enough water for over 1,600 years. That would give far more than enough time to develop strategies to import water from asteroids, comets, or other destinations. In other words, settlers on the Moon will never run out of essential resources.



Illustration of lunar volatiles.

Uses for Lunar Water

Lunar-derived water has multiple uses. By far, the most important use is the refueling of reusable lunar landers thereby turning them into ferries. To achieve this, one simply must electrolyze the water into its constituent parts – hydrogen and oxygen. A variant of Blue Origin’s Blue Moon lander is described in chapter 7 which could use this propellant to ferry crew and cargo modules between high lunar orbit and the surface of the moon.

But water could also be used for sanitation, drinking, and to irrigate plants for food and fiber. Electrolyzed water could provide the oxygen necessary for breathing. Finally, if the harvesting of water was achieved relatively early on then it could be pumped between the outer layers of habitats to provide excellent radiation shielding.

REGOLITH

If there is difficulty with harvesting water ice, then the simplest way of getting radiation shielding is to simply have telerobots either push the lunar regolith onto the top of flat-roofed habitats (e.g. like an air mattress) or drop the regolith within their walls. Placing regolith on top of the habitats would be especially easy to do if those habitats were inflatable and if the telerobots were to push the regolith on top of them prior to inflation. This covering would not only protect against space radiation but also from micrometeorites and provide a good amount of insulation to moderate any temperature extremes.

METALS

Although the LCROSS results show ethylene which can be polymerized into polyethylene plastic, the organics would be better used not for plastics but for other purposes (e.g. CO₂ for plants, oils, solvents, lubricants, etc.). That is because, on the Moon, organics are much more limited than metals. For this reason, on the Moon, everything possible should be made from metals than from plastics.

Unfortunately, we don't know if pieces of nickel-iron meteorites would survive the high impact speed impacts on the Moon or whether they would vaporize altogether. There is unoxidized nanophase iron but that is coated all over the lunar regolith grains thereby making lunar regolith attracted to magnets. So, saving energy by separating unoxidized metals may not be particularly easy.

Alternately, one could just "pay the price" and process certain lunar rocks into metals by heating the rocks to the point where the metal oxides in the rocks break down into unoxidized metals and oxygen which makes up the large majority of the mass of propellant.

Given the Moon's relatively simple geologic processes (as compared to that of the Earth's) there are relatively few types of rocks composed of certain minerals on the Moon. There are the mare basalts, highland plutonic rocks such as anorthosite, KREEP-rich rocks, impact breccias, and granites/felsites, and pyroclastic glasses. Regolith is the thick dirt layer which is typically an average of rocks that have been pulverized and mixed up (gardened) from impacts over the eons.

Distinct rocks have somewhat different mineral concentrations compared to each other so one would want to start with the rocks (as opposed to regolith) and crush them up to have greater yields of certain metals.

Given the types of rocks that there are on the Moon, we should be able to produce iron, aluminum, titanium, calcium, and magnesium. However, unlike on Earth, there are no geologic processes that would produce concentrated ore bodies for certain metals such as copper. However, we could easily ship 100 tonnes of copper which should last for a very long time and/or we could utilize alternatives such as aluminum wiring, which is safe provided electrical work is handled according to strict standards. When done so, the risks drop to nearly that of copper.

OTHER RESOURCES

Silicon

Silicon is useful for both solar panels as well as for electronics. As mentioned above, it is very prevalent in certain, readily available minerals on the Moon. To extract the silicon, a process such as molten electrolysis could be used. Multiple groups have demonstrated the production of solar cells from lunar regolith simulant including Blue Origin, a group in Texas, and two in Europe.

KREEP Rocks

There are rocks located by certain craters on the Moon called KREEP. This is an acronym for potassium (K), Rare Earth Elements, and Phosphorus (P). In agriculture, fertilizer is composed of NPK standing for Nitrogen, Phosphorus, and Potassium. So, for full self-reliance the KREEP rocks would be a useful source of potassium and phosphorus. Nitrogen would come from the ammonia in the ice at the permanently shadowed regions at the poles. All of these fertilizers would be diligently recycled so that we would not have to mine and input large quantities of them into our agricultural system.