Collecting Lunar Hydrogen from the Solar Winds

Joshua Sorell, BSc

Abstract
Hydrogen on the moon is an important part of life on the moon. It can be combined with oxygen to make water or used with oxygen as a propellant. Transportation costs from the earth surface are expensive and charge per kilogram, an alternative source would be useful for Lunar habitation. Solar wind can be used as a source of indirect hydrogen. The Lunar surface is not protected from the Solar wind as the Moon does not possess the magnetic field of Earth and is outside the Earth's field. Solar wind contains 95% protons which interact with the Lunar surface to become hydrogen before being lost to space. Collecting this hydrogen is possible with current technology and materials on the Lunar surface for In Situ Resource Utilization (ISRU) that compares with the current Lunar hydrogen collection plans.

Introduction:
The moon is a hot topic recently as a destination for science. Nations and private corporations are planning to launch to sites on the lunar surface as well as in orbit. This includes notable examples like the Lunar Gateway and the Artemis Accords[1], a program through NASA is an international initiative to put people on the moon. People on the moon is an ambitious plan but it requires infrastructure and resources to support life. This includes things like water, oxygen, radiation shielding, and rocket fuel. These requirements have led to most habitation plans to be on the Lunar South Pole where there has shown to be continuous sunshine, and water[4]. Water is essential on the moon as it provides for many requirements. It can be used as radiation shielding, used for lunar crops, human consumption, and hydrolysed to make hydrogen and oxygen. If we are to occupy other parts of the lunar surface we need another source for this vital resource. The lunar surface is an excellent source for oxygen as it is 45% of lunar soil by mass and there is a device being constructed by nasa to extract it from Lunar regolith[5]. With a source of hydrogen we would be able to create water anywhere on the lunar surface. The sun produces a solar wind caused by the outward expansion of plasma from the sun's corona[2] this solar wind is composed of 95% protons, 4% alpha particles, 1% minor ions[3]. The protons specially are missing only an electron to become hydrogen. The lunar surface is actually an excellent hydrogen producer and actually takes incident protons from the solar wind and reflects back Hydrogen[6]. If we can capture it than we can have another source of hydrogen on the lunar surface.

Solar wind:
Solar wind contains 95% protons that go 400 - 750 km/s away from the sun. They have an average density of 3 - 10 particles/cm^3 at the distance of 1 AU from the sun[7]. As the distance to the sun increases the density of the solar wind decreases. There is also 2 types of solar wind the fast solar wind and slow solar wind. There composition differs as well as there speed. The slow solar wind goes slower around 400 km/s and is denser while the fast solar wind goes around 750 km/s and is less dense[9]. While these both winds are mostly protons/electrons the slow wind contains more Mg/O and comes from a very hot source[9].

Earth's magnetic field creates a bubble that protects the earth from the solar wind. The moon does not have a magnetic field and it is outside of the earth's magnetic field's reach. The solar wind therefore impacts the lunar surface. Surprisingly it does not do so freely, due to the reflection of protons from the solar wind there is a barrier above the lunar surface that prevents all of the solar wind from reaching the surface of the moon[10].

Collection:
In a proton shielding study mylar is permeable to protons at thicknesses from 0 - 10 cm thicknesses[8]. If protons pass through the mylar they will impact the lunar regolith. Lunar regolith documented excellent at converting hydrogen from protons bombardment from the solar wind[6] by adding the necessary electron to make hydrogen. A simple device to collect hydrogen could be a large square sheet of mylar laying across the lunar surface that has the edges tucked into the lunar soil so that it is closed off.

Mylar is known as a container for Hydrogen in balloons and only holds hydrogen for 3-5 days at room temperature and atmospheric conditions. What does this mean for the lunar environment where there is no atmosphere, low pressure, and in the sunlight temperatures of 120 ºC (393K). Helium is well documented in its permeability through Mylar and matches hydrogen closely. Hydrogen is smaller though so its permeability would be greater. Using the permeability equation and the permeation constant for Helium at room temperature K_0 = 1.2E -08 (sccm cm^{-2} cm s^{-1} atm^{-1}) we can calculate for the permeability at the lunar environments temperature.

$$K = K_o e^{\Delta E/RT}$$
$$K = 3.75E - 04\, e^{5.8/1.987*393}$$
$$K = 0.94 (\text{sccm cm}^{-1}\text{ s}^{-1}\text{ atm}^{-1})$$

Where ΔE = activation energy for permeation, $K_{\circ}$ is the permeation constant, T is the temperature in kelvin, R = 1.987 cal/molK. For 4.2mil thickness of mylar and Helium the $K_{\circ}$ = 3.75 E -04 and the ΔE = 5.8. We can calculate the rate of permeation for the conditions on the lunar surface if the hydrogen was contained by aluminized Mylar if we know the area of the collector.

$$Q = KPA/d$$

Where Q = rate of permeation (sccm s^{-1}), P = pressure of gas contained (atm), A = area (cm^2), d = thickness of Mylar (cm).[14] The pressure on the lunar surface is measured to be 2.96E -15 atm on the lunar surface[15].

To calculate the area of our collector required we can take the slowest speed of the solar wind possible as 250 km/s with an average density of 5 particles/cm^3 we can calculate the amount of particles that go through a cm in space in a sec

Velocity of solar wind * particle density = particles per second

2.50×10^7 cm/s * 1.71 particles/cm = 4.27×10^7 particles/second

To figure out how many particles we can compare it to Avagadro's number of 6.02×10^{23} which tells us how many of a particle is a mole of that material. We can see that it is still much smaller than a mole of hydrogen per second. To visualize how reasonable it would be build a collector on the lunar surface we can compare how big of a collector would be created to satisfy human life. Human male's require on average 3.0L of water per day and females 2.2L of water[11]. So if we use the larger amount we can figure out how much water would be required to be made to satisfy on male. Water is approximately 1g/mL so we would need 3000 g of water. Waters molecular weight is 18.015 g/mol and we know that there are 2 hydrogens per oxygen molecule and hydrogen is 2.015 g/mol

Grams of hydrogen / Grams of water = 2 * Hydrogen molecular weight / water molecular weight

Grams of Hydrogen = Grams of water * (2 * Hydrogen molecular weight / water molecular weight)

Grams of Hydrogen = 3000 * ((2 * 2.015 g/mol) / 18.015 g/mol

Grams of Hydrogen = 671g of hydrogen

Now we can solve for the required surface area to collect 671g of hydrogen per day or 2.01×10^{26} particles of hydrogen. We know that protons only make up 95% of the solar wind so we can use 95% of our particle density of the solar wind[3] or 1.62 particles/cm for protons. Solving for how much mass of hydrogen we can get at different areas we get using the mass flow rate formula.

Mass flow rate/density of hydrogen * velocity = Area needed

671g hydrogen/day / 1.59×10^{-17} g/m² * 2.16×10^{10} m/day = Area needed

1.95×10^9 m² = area needed

This is equal to an area that has 44.2 km per side square for enough hydrogen for water for 1 male per day.

Hydrogen collected per day (g)	Areas (m²)	Time to reach 671 g hydrogen (Days)
3.43E-06	10	1.95E+08
3.43E-05	1.0×10^2	1.95E+07
0.34	1.0×10^6	1954.56
137.32	4.0×10^8	4.89
549.28	1.6×10^9	1.22
671.00	1.9×10^9	1

1343.19	4.0×10^9	0.49

Table 1.0 Table showing the grams of hydrogen collected per day due to the size of collector. The speed of the solar wind is 250 km/s and the mass of the protons is 4.75 particles/cm³

We can now calculate how much the rate of permeability would be for the mylar on the lunar surface, assuming that the area is volume under the mylar sheet is 1cm than we can solve for the pressure under the mylar sheet.

$$pv = nrt$$

$$p * 1.96E + 13 = 333.2\,mol * 8.314\, m_2\, kg\ s_{-2}\ K_{-1}\ mol_{-1} * 393K$$

$$p = 5.57E - 08\,pa$$

or

$$p = 5.5E - 13\ atm$$

Where p is pressure in pascals, v is volume, n is mols of hydrogen, r is the molar gas constant, and t is temperature in kelvin.

$$Q = KPA/d$$

$$Q = 0.94 * 5.47E - 13 * 1.96E + 13 / 0.01cm$$

$$Q = 1005\ cm^3/s$$

Q is the rate that the hydrogen leaving the volume of hydrogen contained under our Mylar sheet so it would take. This would only be a maximum rate that would decrease as the pressure decreased within the Mylar container. The temperature would also affect the permeability rate so over Lunar night the permeability would decrease.

$$total\ volume/flow\ rate = time\ to\ empty$$

$$1.96E + 13\ cm^3/1005\ cm^3/s = 1.95E + 10\ seconds$$

Or

617 years to empty

Pressure Difference (atm)	**Amount of Hydrogen (mols)**	**Rate of Diffusion (cm³/s)**	**Time Till Empty (Days)**
5.47E-13	333.22	1.01E+03	2.25E+05
4.39E-12	2665.8	8.10E+03	2.80E+04
7.69E-12	4665.1	1.42E+04	1.60E+04

Table 1.1 Amount of hydrogen collected and calculated diffusion rate with time to complete diffusion of collected hydrogen from mylar container with mylar thickness of 4 mil at 393K with a sun-facing collector area of 1960km².

Conclusions:

It is possible to collect hydrogen from the solar wind. While this is a noticeable amount it is not enough to support a large population with hydrogen if using it in water production. This hydrogen is possible to be collected with a simple method of using Mylar sheet laid across the Lunar surface as the mylar would be permeable to protons and would contain the converted hydrogen at low pressures and the high sunlight temperatures on the lunar surface. While this may not produce enough for sustainable water production on the lunar surface. This could provide a supplementary backup source in case of transportation shortages or for production of hydrogen for other uses. Such as methane production or in the creation of radiation shielding. Shielding with high hydrogen content to make more effective solar radiation shielding[14].

If not using this hydrogen collection method for water production then the most useful size could be 400 km^2 to collect about 137g of hydrogen per day. This compares to the other accepted method of Lunar hydrogen collection through processing regolith. This process uses the collection of regolith and heating it to 900ºC to release hydrogen with a calculated yield of 1kg of hydrogen per 20000kg of regolith[17]. Both methods could have use on the Lunar surface but a passive method is cheaper method of hydrogen collection because it would not require the infrastructure required to process such large quantities of regolith.

References:

1: NASA artemis accords: https://www.nasa.gov/specials/artemis-accords/index.html

2::https://www.jpl.nasa.gov/nmp/st5/SCIENCE/solarwind.html#:~:text=The%20solar%20wind%20is%20created,lines%20that%20extend%20radially%20outward.

3: Solar wind Composition; https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/95RG00122

4: Map of Moon’s water near its south pole: https://www.nasa.gov/feature/ames/study-reveals-map-of-moon-s-water-near-its-south-pole

5: Oxygen extraction from lunar samples:
https://curator.jsc.nasa.gov/lunar/lnews/lnmar97/oxygen.htm

6: Hydrogen offers a new way to study the moon:
https://www.esa.int/Science_Exploration/Space_Science/Hydrogen_offers_a_new_way_to_study_the_Moon

7: The Solar Wind: https://umbra.nascom.nasa.gov/spartan/the_solar_wind.html

8: Optimization of shielding to reduce cosmic radiation damage to packaged semiconductors during air transport using Monte Carlo simulation:
https://www.sciencedirect.com/science/article/pii/S1738573319309878#:~:text=Materials%20with%20high%20atomic%20numbers,neutrons%20%5B18%2C19%5D.

9. Solar wind : http://solar-center.stanford.edu/FAQ/Qsolwindcomp.html

10: Bow shock protons in the Lunar environment:
https://adsabs.harvard.edu/full/1975Moon...14...19B

11: [How much water do we really need to drink?] ;
https://pubmed.ncbi.nlm.nih.gov/20356431/

12: Hydrogen; https://pubchem.ncbi.nlm.nih.gov/compound/Hydrogen

13: Water; https://pubchem.ncbi.nlm.nih.gov/compound/Water

14: Permeation of argon, carbon dioxide, helium, nitrogen, and oxygen through Mylar windows; http://mu2e.phy.duke.edu/cw/misc/Mylar_permeation_BNL.pdf

15: Perturbing the Mass and Composition of the Lunar Atmosphere During the Artemis Surface Missions;
https://www.lpi.usra.edu/announcements/artemis/whitepapers/2011.pdf

16:Mylar: Physical-Thermal Properties; https://usa.dupontteijinfilms.com/wp-content/uploads/2017/01/Mylar_Physical_Properties.pdf

17: Harry Jones; Should Oxygen, Hydrogen, and Water on the Moon Be Provided by Earth Supply, Life Support Recycling, or Regolith Mining?; July 30, 2021;
https://ntrs.nasa.gov/citations/20210019592