Application of Solar Hydrogen Production and Hydrogen Energy Storage in Outer Space

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Abstract. The pursuit of space colonization has captured humanity's imagination, leading us to imagine a future in which humans inhabit distant celestial bodies. However, such ambitious efforts raise questions about the sustainability of life in these harsh and isolated environments. Among these issues, a reliable and renewable energy source is essential. In this context, hydrogen is essential to the space colonization equation. Hydrogen, as an energy carrier, offers numerous compelling reasons for its essential role in the future of space colonization. First and foremost, hydrogen boasts an unparalleled versatility that aligns with the multifaceted demands of space colonization. In space, hydrogen can be employed in various applications, including power generation, propulsion, and life support systems. In addition to its versatility, hydrogen is a crucial chemical feedstock for various industrial processes. These processes are pivotal in sustaining human life and facilitating scientific endeavors in space. We will explore hydrogen's unique advantages and potential to reshape how we approach the challenges of inhabiting other worlds. Moreover, we investigate the utilization of these local resources for hydrogen production and the technological methods and challenges associated with each approach. By understanding these methods and their limitations, we aim to contribute to the foundation of knowledge necessary for sustainable space colonization.In conclusion, this paper explores the pivotal role that hydrogen plays in the future of space colonization. It underscores the significance of harnessing local resources for hydrogen production on the Moon and Mars, offering solutions to the challenges that lie ahead. Through interdisciplinary research and innovation, we strive to unlock the full potential of hydrogen as we embark on this epic journey into the cosmos..

Keywords: Hydrogen; Electrolytic hydrogen production; Hydrogen storage; Hydrogen production on Mars.

1. Introduction

The vision of space colonization has evolved from science fiction into a tangible and strategic pursuit, with the Moon and Mars emerging as primary destinations for future human settlements and scientific exploration. These extraterrestrial frontiers, however, present us with an array of unprecedented challenges, chief among them being the imperative need for a dependable and sustainable energy source. In this context, hydrogen is an indispensable element in the grand equation of space colonization.

The indispensability of hydrogen in the realm of space colonization is underpinned by a multitude of compelling reasons. Hydrogen is characterized by its exceptional cleanliness and unparalleled versatility, which align perfectly with the multifaceted demands of space colonization. In the vast expanse of space, hydrogen can be harnessed for many applications, including power generation, propulsion systems, and life support. Furthermore, using fuel cells allows for the reliable conversion of hydrogen into electricity, offering a dependable and continuous power source for critical systems. Moreover, it serves as a vital chemical feedstock, facilitating various industrial processes crucial to human survival and scientific exploration in space.

As space exploration advances, the question of resource utilization becomes paramount. In this regard, both the Moon and Mars hold distinct promise. The Moon houses substantial reserves of water ice within permanently shadowed craters, while Mars possesses significant quantities of methane in its atmosphere and subsurface.

Furthermore, this paper will explore and utilize these local resources for hydrogen production, providing a comprehensive analysis of the technological methods and challenges associated with each approach.

2. Literature review

2.1. Hydrogen energy

Hydrogen energy is a form of energy that generates electricity or heat energy by reacting hydrogen with oxygen. It has the characteristics of high energy density, pollution-free emissions, renewability, and only produces water during the utilization process. According to “New Horizon”, Hydrogen energy has various advantages. It is derived from fossil fuels and renewable sources like wind and water, offering a versatile and clean energy solution. With its remarkable calorific value surpassing even LPG and gasoline, hydrogen stands as a potent fuel source. Its clean and recyclable nature, characterized by colorlessness and non-toxicity, allows it to burn into harmless water, and its recyclability through electrolysis furthers its sustainability. The applications of hydrogen, from heat and mechanical work to fuel cells and structural materials, showcase its adaptability. Additionally, hydrogen's proficiency in energy storage facilitates continuous supply, long-distance transportation, and swift replenishment, rendering it a promising option for energy needs. Notably, hydrogen's safety profile outshines steam or oil leakage, adding to its allure as an energy resource [1].

Hydrogen energy is utilized as a clean and versatile source of fuel and electricity generation, characterized by its potential for zero-emission energy production through hydrogen fuel cells and its ability to be produced from various renewable sources. Characterized by its clean combustion, high energy density, and potential for zero emissions, hydrogen has emerged as a versatile energy carrier. It finds applications in various sectors, including transportation, electricity generation, industrial processes, and even as a feedstock for chemical production.

2.2. Hydrogen production technology

2.2.1 Electrolytic Hydrogen Production

Ou's research in 2009 provides a summary of the characteristics of Electrolytic Hydrogen Production [2]. This method is extensively employed for converting renewable resources into hydrogen. The process is known for its relative simplicity. However, it requires a substantial amount of external energy to facilitate the decomposition of water, which results in the generation of hydrogen and oxygen gases through electrolysis.

In conclusion, electrolytic hydrogen production is a common and effective method of generating hydrogen. Through electrolysis, hydrogen and oxygen can be separated from water molecules. When implementing the process, critical parameters such as current density and temperature must be considered. Applying electrolytic hydrogen production technology improves clean energy and reduces reliance on traditional energy sources [3].

2.2.2 Steam Methane Reforming for Hydrogen Production

Steam methane reforming (SMR) is a common and economically efficient method of hydrogen production. Its basic principle involves a chemical reaction between natural gas (mainly methane) and steam under high-temperature conditions to produce synthesis gas, which is then used for hydrogen production. This process primarily involves two key steps: reforming reaction and water-gas shift reaction [4].

Overall, steam methane reforming is an important hydrogen production technology with mature industrial applications. Through proper reaction control and technological improvements, hydrogen production efficiency and catalyst lifespan can be further enhanced. As the demand for hydrogen energy continues to increase, steam methane reforming technology holds promise for playing a significant role in developing and utilizing hydrogen energy.

2.2.3 Hydrogen production from solar energy

According to different solar energy conversion pathways and principles, solar hydrogen production technologies can be classified into four types, including photocatalytic hydrogen production, photoelectrochemical water splitting, solar thermochemical hydrogen production and photobiological hydrogen production technology. Each of these technologies has unique advantages and applicable ranges, playing crucial roles in promoting clean energy development and facilitating the utilization of hydrogen energy.

2.3. Hydrogen storage

Technologies for storing hydrogen include the following three types:

First, high pressure gaseous hydrogen storage is a technology that compresses hydrogen and stores it in a pressure tank, with the amount of hydrogen stored proportional to the pressure. Under high pressure, the volume of hydrogen gas significantly decreases, allowing for storing a greater amount of hydrogen in relatively smaller storage containers [5].

Low-temperature liquid hydrogen storage is a technology where hydrogen is cooled to -253 ℃ to become a liquid and then stored in insulated containers. Liquid hydrogen has a much higher density than hydrogen gas at standard temperature and pressure, making it advantageous for unit hydrogen storage.

Organic liquid hydrogen storage technology is an innovative approach to store and release hydrogen gas using certain organic compounds as the storage medium. In this method, hydrogen is chemically absorbed or adsorbed into the molecular structure of the organic liquid, forming a stable hydrogen-rich compound. Organic liquid Hydrogen technologies technology has the advantages of high density of hydrogen storage, safe storage and transportation, recyclability, fast dehydrogenation response, and can be transported as safely and efficiently as oil. By using the existing gasoline transportation mode and gas station structure, the cost of using hydrogen energy will be greatly reduced in the future.

3. Discussion

3.1. Outer Space Hydrogen Energy Base (OSHEB)

3.1.1 Basic Introduction to the hydrogen energy base

Outer Space Hydrogen Energy Base (OSHEB) is a large cluster of hydrogen energy manufacturing, storage, and transportation units that will be widely built on different planets or satellites in the future [6].

OSHEB will have a significant impact on humans. Firstly, this ensures as much independence as possible in the energy sources of alien colonies, which means they do not require energy supply from Earth and can achieve self-sufficiency in energy, improving the sustainability of human civilization in outer space and on outer planets. Secondly, humans can achieve industrialization and urbanization on Mars or the Moon, allowing for positive population growth and good economic development. Thirdly, human colonies primarily relying on hydrogen energy will not cause pollution or other adverse effects on their settlements.

3.2. OSHEB’s hydrogen production on the Lunar through the water ice

It is not difficult to find that most of these hydrogen production methods require a basic substance - water, which may not be good news for most non-Earth planets in the solar system. However, according to two studies mentioned in Maya Wei-Haas 's article Water on Moon's surface may be more abundant than once thought published in National Geographic, there is a significant amount of water present on the lunar surface.

There is clear evidence that water molecules attach to soil particles on the moon [7]. The shadow area where the moon can produce hydrogen ice is approximately 15400 square miles: an area equivalent to approximately 7500000 football fields. There are multiple explanations for the existence of water on the moon, “Large craters with terraced rims block sunlight from ever reaching inside. These areas are called permanently shadowed regions, or PSRs.” The reason why scientist found water in these PSRs regions, Mehta explained, "the solar wind—more specifically, protons emitted by the Sun—constantly bombard the surface. Some of these protons interact with oxygen molecules in the lunar soil to produce water.”

According to Commercial lunar propellant architecture: A collaborative study of lunar propellant production written by George Sowers and the dozens of other scientists, they proposed a method for obtaining water from lunar soil:

Large towers with concave mirrors on the top would be erected and installed around the crater edges to reflect sunlight down into permanently shadowed regions. This energy would heat the lunar soil to 220 K (-53.15 °C), warm enough to make the water ice sublimate into vapor. A tent cover over the soil would trap and capture this water vapor, which would be moved into large aluminum units to freeze back into ice. “Haulers (maybe robotic, or maybe driven by astronauts) would drive the ice out to a facility where it could be purified. The water would be split into hydrogen and oxygen through electrolysis.”

3.3. Hydrogen production on Mars through the SMR

3.3.1 Methane on the Mars

Methane on Mars is a notable gas with potential implications for the presence of life. Europe’s Mars Express probe measured 15.5 parts per billion in the atmosphere above the Gale Crater on June 16, 2013. The presence of methane in the vicinity was confirmed by readings taken 24 hours earlier by NASA's Curiosity rover. The sources of Martian methane are still under investigation, with hypotheses including biological metabolism, subsurface hydrothermal activity, and geological processes.

It is necessary to explore the feasibility of using methane on Mars for SMR hydrogen production. Steam methane reforming (SMR) is a process in which methane from natural gas is heated with steam, usually with a catalyst, to produce a mixture of carbon monoxide and hydrogen used in organic synthesis and as a fuel.

3.3.2 Explore the Mars OSHEB base on SMR

Since the source of methane on Mars is the leakage of underground methane from the surface to the atmosphere, we need a method to detect the location of the leakage point to collect methane gas. It should be noted that the location of methane leakage points on Mars cannot be detected by methods such as atmospheric spectral analysis of Mars orbiting satellites. Winds and sandstorms can cause methane gas to deviate from its surface leakage point.

In the industrial field, steam methane reforming (SMR) for hydrogen production involves detailed steps. Initially, the supply of raw materials involved methane and water vapor, which were pre-treated and may be purified in storage tanks or storage facilities to ensure the quality of the raw materials. Then, the pre-treated methane and water vapor enter a high-temperature and high-pressure tubular reactor, and under the action of a catalyst, undergo steam methane reforming reaction to generate hydrogen and carbon monoxide. The generated gas mixture enters the heat exchanger for cooling and utilizes heat recovery technology to improve energy efficiency [8].

Next, during the water gas transformation phase, the generated water gas may react with water vapor through further reactors to convert carbon monoxide into carbon dioxide and more hydrogen. Subsequently, the gas is separated and purified, and hydrogen is separated from other gases using adsorbent or membrane separation technology. In some cases, CO2 removal devices may be required to remove the remaining carbon dioxide. The purified hydrogen enters the hydrogen compression device to compress it to the required pressure, usually involving a pressure vessel. The compressed hydrogen gas is stored in high-pressure containers and can be transported to various industrial locations through pipelines. In summary, the industrial SMR hydrogen production process is a complex process that involves multiple steps and related containers, aimed at producing high-quality, high-pressure hydrogen to meet industrial needs.

Given the limited sunlight and frequent sandstorms on Mars, it is crucial to consider reliable and sustainable power sources. The proposal may overestimate the methane reserves on Mars and the feasibility of producing a large amount of hydrogen energy.

3.4. Ice layer under Mars

There are three main sources of ice on Mars. One is the ice sheet located in the North and South Poles, the cryosphere of the subsurface layers, and the Glacier like forms in mid latitudes and a few equatorial areas [9].

Research from Mars missions has found evidence of extensive, relict ice-rich deposits in the middle and lower mid-latitudes of Mars. The study discusses various techniques for ice characterization on Mars, including neutron detection, thermal analysis, geomorphic mapping, radar surface analysis, and radar subsurface dielectric analysis. The study has found evidence of extensive, relict ice-rich deposits in the middle and lower mid-latitudes of Mars.

3.5. Extracting the ices

In a document released by NASA 2016 titled "Mining" Water Ice on Mars: An Assessment of ISRU Options in Support of Future Human Missions, "Stephen Hoffman and two other scientists mentioned the mining strategy for ice resources on Mars.

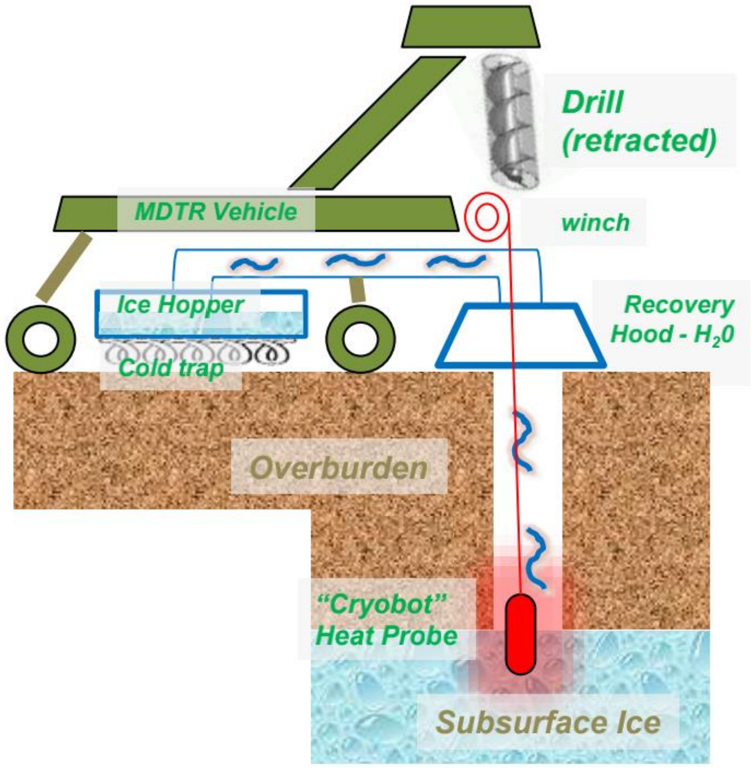

Figure 1 The picture showing how NASA's Mars ice mining vehicle works

Figure 1 shows how NASA's Mars ice-mining vehicle works. Once enough ice has been collected, specialized mining vehicles or robots transport these ice blocks to nearby hydrogen processing plants. At these facilities, a rigorous three-step process consisting of purification, melting, and electrolysis, will be executed to extract hydrogen energy from the ice blocks. This method is crucial to harnessing hydrogen as an alternative energy source, which holds immense potential for a more sustainable future.

4. Conclusions

In summary, this paper explores a spectrum of pioneering approaches aimed at revolutionizing the way we harness hydrogen energy in the context of space exploration and colonization. The objective is to establish sustainable, self-reliant energy sources for the nascent colonies beyond our planet's boundaries, under the umbrella concept of OSHEB.

The first method, which utilizes cutting-edge optical methods to extract water ice from lunar craters shrouded in perpetual shadow, promises to secure a critical water source. This water can be subjected to electrolysis to produce both hydrogen and oxygen, thus addressing the core energy needs of future lunar and interplanetary settlements. The second method capitalizes on the adaptability of Mars rovers to venture underground on the Martian surface, capturing methane emissions and converting them into hydrogen using the advanced Steam Methane Reforming (SMR) technique. This approach represents a pivotal step towards sustainable energy production on Mars, albeit necessitating a reliable water source for the hydrogen production reactions, a challenge that warrants further investigation. The third method, which involves the pioneering extraction of groundwater ice on Mars, presents an innovative pathway to secure the essential raw materials for hydrogen energy production in a Martian environment.

In conclusion, the methodologies delineated within this paper underscore the paramount role that hydrogen energy can assume in advancing and sustaining prospective space colonies. At the core of this endeavor lies the audacious aspiration to propel humanity into a genuinely sustainable and self-reliant extraterrestrial era. As we venture further into the uncharted cosmos, the transformative potential of hydrogen energy emerges as an illuminating guide, illuminating the path toward a thriving and enduring human presence in the vast expanse of outer space.

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