Obtaining resources on Mars

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Abstract

In any consideration of long term (one or two years or longer) human activities on Mars, it is essential to optimize and develop sustainable methods of obtaining essential resources from the surface of Mars. The three primary resource requirements for supporting and sustaining human life on Mars are: water, oxygen, and fuel. These resources are of utmost importance for future scientific exploration missions, permanent colonization, and the development of sustainable city infrastructure. This paper reviews the current state of knowledge, systems, methods, and technologies for optimal near-term resource production on Mars.

Contents

1 Introduction

The exploration of Mars has been widely considered by many to be the next step to advancing humankind. However the exploration of Mars requires many considerations to be made to support human life. The collection and/or production of essential resources such as water, oxygen, and fuel, is crucial to the possibility of humans inhabiting Mars and making Mars habitable for life. Water and oxygen are both essential parts of sustaining human life, being vital to the existence of life. Additionally, fuel is crucial for the transportation, both interplanetary and locally. Furthermore, fuel would be essential to exploration and the production of energy that would run systems that help sustain human life.

Part I
Water

Water is an essential part to sustaining life, and will need to be produced, collected, or brought to Mars if the colonization of Mars is to be a possibility. The transportation of water to Mars from Earth would be expensive and inefficient, making it an impractical solution. The production of water is possible, however is expensive and usually creates unwanted byproducts. This means that the collection of water on Mars will be almost essential to the sustaining of life on Mars. Mars is known for its frozen water which would make it easier for the collection of water on Mars. Humans are estimated to only survive 3 days without water, making it a necessity for inhabiting Mars.

2 Water production on Earth

Around 71% of the Earth is covered in water, making it easy to collect and utilize water on Earth. Around 97% of that water is found in the oceans, which with its dissolved salt, makes it not directly drinkable and usable by humans. However, this is still enough water for humans to live off of. Once used, the water gets filtrated and recycled, usually using a combination of filtering systems such as reverse osmosis or charcoal.

3 Water production on Mars

Unlike Earth, Mars only has an estimated 14% of its surface being water. More than 5 million cubic kilometers of ice have been identified at or near the surface of today's Mars. Melted, this would be enough to cover the whole planet to a depth of 35 meters. Even more ice is likely to be locked away in the deep subsurface of Mars. However, most of this ice is soaked into the crust, making it difficult to collect efficiently. Once this water is collected, it could be recycled similarly to Earth.

4 Finding water ice

The only source of visible water on Mars is the North pole's ice cap which contains around 821,000 cubic kilometers of frozen water. Past Mars rovers such as NASA's Phoenix lander[7] scrapped up ice on the surface of Mars, confirming the existence of water ice near the surface, as well as NASA's Mars Reconnaissance Orbiter (MRO) which has taken images from space of meteor impacts that have excavated water ice. To find ice that astronauts could dig up, scientists have relied on two heat sensitive instruments, MRO's Mars Climate Sounder and the Thermal Emission Imaging System (THEMIS) camera on Mars Odyssey. Buried ice is able to change the temperature of the Martian surface, making ice detectable using heat sensitive instruments. Additionally, data from the Gamma Ray Spectrometer (GRS) onboard Mars Odyssey has helped detected water ice near the Martian surface. [5] [6]

5 Known sources of water ice

Most water detected on Mars has been located near to the poles due to the lower temperatures allowing the water vapor in the atmosphere to freeze. However, inhabiting the poles would be too cold to sustain life so scientists have decided that the northern and southern mid-latitudes would be more practical. There is also a preference for the northern hemisphere due to the lower elevation and denser atmosphere which would aid in slowing a landing spacecraft.

The cool colors are closer to the surface than warm colors, the black zones indicate areas where a spacecraft would sink into find dust, and the outlined box represents the ideal region to send astronauts for water ice.

6 Water collection

To collect the frozen water, the ice must be heated to temperatures well above temperatures that can be found on Mars. There are many proposed methods of heating the water. One proposed method is the use of a system known as a Rodriguez well, which is currently in use on Earth in places like Antarctica to access water. It works by submerging heated rods into drilled holes which melts the ice, creating a well of

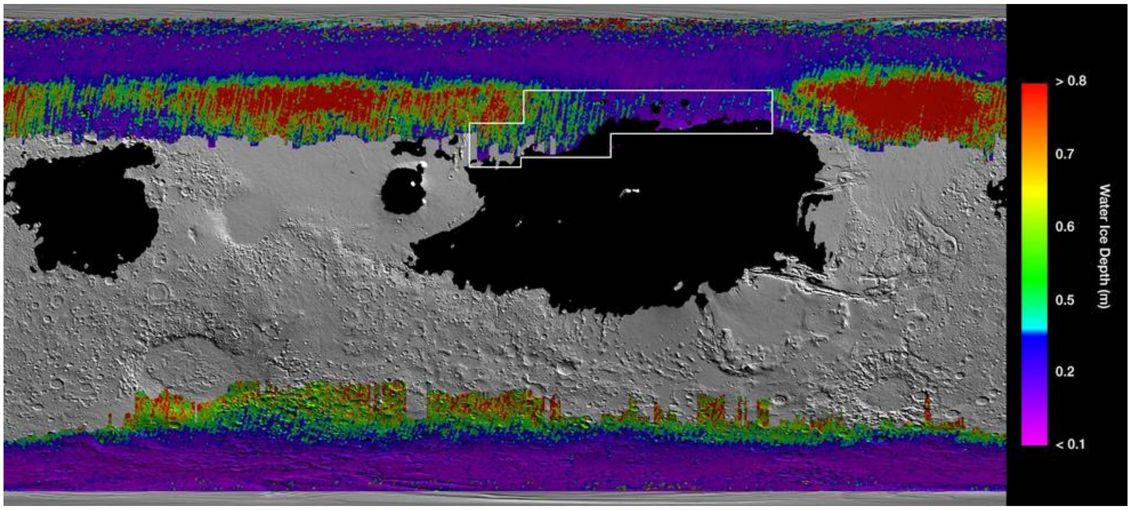

Figure 1: Depth of known water on Mars[8]

liquid water that can be pumped up to the surface.[10] Another possible method of collecting the water is microwaving the ice. This would require less digging than other excavating methods. Ice doesn't absorb microwaves well so the microwave beams will instead heat up the rock, which heats the ice upon contact. After collecting the water, the water must be filtrated and purified to remove any chemical impurities such as heavy metals or salts. In theory this could be done in a similar manner to processing on Earth.[4]

7 Environmental factors

The removal of water ice from under the surface of Mars could possible have unintended consequences such as damage to the surface or if enough ice is removed, could weaken the structure of the surface in the area, making it inhabitable. Additionally, the obtaining of ice would also use a lot of energy, also possibly damaging the surrounding environment.

8 Economic factors

Collecting water from Mars will probably be the most cost effective method of obtaining water on the surface of Mars. The cost to transport water from Earth is much larger than the cost of creating infrastructure on Mars to collect and purify water. However, there still would be a cost involved in making and developing the required infrastructure to purify and collect water on Mars. There still needs to be research and development done in making water purification systems as well as water collection methods that work on Mars both effectively and efficiently.

Part II

Oxygen

Oxygen is an essential part to human survival, allowing for the processing of glucose and energy in major components of our body such as the brain. Without oxygen, the brain cannot convert glucose into energy, resulting in inadequate energy to power the brain's cells. Earth's atmosphere is made of approximately 21% oxygen, allowing for humans to breath the air. However, Mars' atmosphere is made up of primarily CO_2, making up 96% of the atmosphere with oxygen only making up 0.13% of the atmosphere. This means that the production of oxygen on Mars will be crucial if we are to sustain human life on Mars.

9 Methods of obtaining oxygen

Oxygen can't be efficiently transported from Earth and can't be collected on Mars meaning the only way to obtain oxygen on Mars is to produce it. The most researched and developed method of obtaining oxygen on Mars is producing oxygen by splitting the carbon dioxide found in the atmosphere into oxygen and carbon.

9.1 Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

The MIT led Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) has been successfully making oxygen from Mars' $CO_{@}2$ rich atmosphere since April 2021, about two months after it touched down on the Martian surface as part of NASA's Perseverance rover and Mars 2020 mission. It works by first drawing in Martian air in through a filter that removes dust and other contaminants. The air is then pressurized, and sent through the Solid OXide Electrolyzer (SOXE), an instrument that electrochemically splits the CO_2 into oxygen ions and carbon monoxide. The oxygen is then combined to form O_2 which MOXIE then measures for quantity and purity before releasing it back into the air, along with carbon monoxide and other atmospheric gases.[2][1]

9.1.1 Advantages

- Compact
- Highly tested
- Well funded
- Works in extreme conditions

9.1.2 Disadvantages

- Small
- Needs to pressurize and heat martian air, consuming energy and requiring more parts
- Is still a scaled down model

9.2 Plasma reactor

Another newer development could more effectively produce oxygen on Mars. Using a plasma reactor to split the carbon from oxygen could possibly be more efficient than using MOXIE's approach. A beam of electrons, accelerated to a specific energy level, can split carbon dioxide into its component ions, just like MOXIE. Additionally, a plasma reactor would be well suited to the less dense Martian atmosphere, being able to create and accelerate a beam of electrons in the thin air. Unlike MOXIE, the compressing and heating of the air is not necessary. However, the machine would need a portable power source and a place to store the oxygen it produces, which could end up making the machine larger than MOXIE. This concept could also be applied to other atmospheric molecules such as nitrogen to create fertilizer.[3]

9.2.1 Advantages

- Could have multiple usages
- Doesn't need to compress or heat the Martian air

9.2.2 Disadvantages

- The technology is much less developed than MOXIE
- Hasn't been well funded like MOXIE
- Hasn't been as rigorously tested

10 Possible usage of leftover carbon

When converting the CO_2 into oxygen, it leaves carbon as a side product that could possibly be used for other applications. Carbon can be used for many different things. The carbon could be turned into graphite which can be used as a high temperature lubricant, making graphite electrodes which are used to produce aluminum by passing an electric current through molten cryolite, Na3AlF6, mixed with Aluminum oxide, making the "brushes" in DC electric motors, as well as making graphite rods which are used to control the rate of fission in nuclear power plants by slowing down the neutrons. Additionally, carbon can be made into carbon fiber which could have many use cases in developing infrastructure on Mars. It can also be infused with iron to make steel.

11 Environmental factors

Running these machines that convert CO_2 into oxygen and carbon monoxide uses a lot of energy that, deepening on how it was produced, could have impacts on the Martian environment. Additionally, the large scale production and manufacturing of such machines could also have a toll on the environment. However, this would make the environment more usable for humans and other life forms, allowing for oxygen to be breathed.

12 Economic factors

The cost of research and development for these technologies could be in the millions of dollars, especially if they need to be tested on Mars like MOXIE. Additionally, these machines must be transported to Mars from Earth which would add to costs. There will also be costs connected to the storage of oxygen and containing the oxygen, not letting it escape into the atmosphere, requiring air tight seals, adding to manufacturing, research, and development costs.

Part III
Fuel

Fuel can be used for both transportation and exploration of the planet as well as for the production of energy to sustain a human population on Mars.

13 Fuel for transportation

The interplanetary travel from Mars back to Earth as well as local travel on planet would be essential to the exploration of Mars as well as the colonization of Mars. A trip from Earth to Mars and back to Earth would require fuel to produced or found on Mars as it would be too heavy to bring the fuel needed for the return trip.

13.1 Methane

Methane has been considered by many as a possible source of rocket fuel for Mars expeditions. Methane is an easily producible fuel on Mars, making it an ideal choice for fuel. Methane has a higher specific impulse, the measure of the efficiency of a rocket engine than kerosene, having a specific impulse of 370s, making it a better rocket fuel.

13.1.1 Atmospheric collection

Even though collecting methane from the Martian atmosphere would be theoretically possible, it would be incredibly inefficient and would not be worth it due to the low amount of methane in the atmosphere.

Methane only makes up around 0.00000004% of the Martian atmosphere. The much more effective method of getting methane on Mars would be through the process of electrolysis of carbon dioxide with water.

13.1.2 Electrolysis of carbon dioxide

A well known method of creating methane from carbon dioxide would be from reacting the carbon dioxide with hydrogen to make methane and water. This is known as the Sabatier reaction. An advantage of the Sabatier reaction is that the water generated can be split again and pumped back into the reaction to continue generating more oxygen and fuel.

The reaction starts off by using electrolysis to split water into hydrogen and oxygen. Then, by mixing the hydrogen gas collected from the electrolysis with carbon dioxide in the atmosphere at high temperatures across a nickel catalyst brought from Earth, the Sabatier process generates drinkable water and methane that can be used as rocket fuel. This water can also be pumped back into the system and undergo the process of electrolysis again, leaving oxygen.

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

However, this uses a lot of energy to heat up the gases so many theorize utilizing large solar infrastructure to power the system.

13.1.3 Advantages

- Creates the needed methane
- Creates additional resources that can utilized such as water or oxygen
- Fairly straight forward process

13.1.4 Disadvantages

- Uses a lot of energy
- Uses more water than is created
- Requires nickel catalyst brought from Earth

13.1.5 Environmental factors

Will require lots of energy as well as resources, possibly damaging Mars' or Earth's environment. It would also take CO_2 out of the atmosphere, possibly leading to unwanted side affects. However, this process would make the Martian environment more habitable for humans, allowing for the gathering of essential resources on Mars. Additionally, the burning of methane does not have major impacts on the environment unlike propellants such as RP-1.

13.1.6 Economic factors

The cost of making the infrastructure of this process would be quite large, especially including the large energy requirements that must be met for the reaction to occur. However, the process would also allow for humans to live sustainably on Mars without separate systems for oxygen and/or water.

13.2 Biofuel

Producing biofuel on Mars could be accomplished by transporting two microbes to Mars. The first would be cyanobacteria (algae), which would take CO_2 from the Martian atmosphere and use sunlight to create sugars. The second would be an engineered E. coli that converts those sugars into a propellant for rockets and other propulsion devices. The propellant, which is called 2,3-butanediol, and on Earth, is used to make polymers for production of rubber. Additionally, the process generates excess clean oxygen that could be used for other purposes. Due to the lower gravitational acceleration of Mars, less efficient rocket propellants could be considered. Using sunlight, carbon dioxide, and water, the cyanobacteria are grown as a feedstock for the engineered E. coli that produces 2,3-BDO.[9]

13.2.1 Advantages

- Uses easily found resources on Mars
- Doesn't require external energy other than sunlight
- Also produces oxygen

13.2.2 Disadvantages

- Not yet tested on Mars
- Not as efficient as some other fuels

13.2.3 Environmental factors

The introduction of microbes to the Martian surface could have unintended side affects on the Martian environment. The use of microbes that can convert sunlight into usable energy would remove extra infrastructure that would require damaging the Martian environment.

13.2.4 Economic factors

Using biofuels would be much cheaper than bring fuel from Earth to Mars. It would only require bringing 2 microbes to Mars. Additionally, it doesn't require large amounts of infrastructure such as solar farms to produce energy to power the system. However, there will be costs involved in the research and testing of these microbes so that they will be able to survive on the Martian surface.

14 Energy

A reliable source of energy is essential for supporting human life on Mars, powering systems required for survival such as the production of oxygen or water. There are many methods of producing usable energy currently in use on Earth, mostly being produced or utilized in the form of fossil fuels such as oil or coal. However, there are no known fossil fuels on Mars, and the transportation of fossil fuels to Mars is infeasible and unsustainable. Other energy production methods include nuclear power, renewables such as solar or wind, and biomass. The use of biomass on Mars is impractical, as well as wind due to the less dense atmosphere, meaning the only options are nuclear power and solar.

14.1 Nuclear

Nuclear power currently makes up around 10% of the Earth's global energy supply, being produced in over 440 reactors. It is the second largest source of low-carbon power after hydro power at 16.6%. Nuclear energy harness the large amounts of energy from atomic reactions. There are 2 types of nuclear power, fusion and fission. Fission harnesses energy from the radioactivity of large atomic nuclei such as uranium-235 or plutonium-239. Fusion harnesses the energy released when 2 atomic nuclei bond, typically isotopes of hydrogen such as tritium or deuterium, producing large amount of energy. However, fusion energy is still highly experimental, with the largest experiment being ITER's tokamak reactor in France. Both kinds of reactors would require large amounts of infrastructure to be built, as well as research and development into having these systems work on Mars. Nuclear reactors would be a sustainable, long term solution to energy on Mars.

Fission reactors would require bringing fuel, typically uranium-235 or plutonium-239, from Earth to be used on Mars. No uranium or plutonium has been found on Mars yet. Fission also requires the careful disposal of radioactive waste.

Fusion reactors on the other hand don't need anything other than their fuel, typically isotopes of hydrogen, which can theoretically be produced on Mars from hydrogen produced through the electrolysis of water.

14.1.1 Advantages

- Long term energy source
- Sustainable
- Low amounts of fuel needed for large amount of energy
- Efficient

14.1.2 Disadvantages

- Expensive to make
- High research and development costs
- Creates radioactive waste

14.1.3 Environmental factors

The use of nuclear energy would create radioactive waste that would need disposing of, possibly damaging the Martian environment. The mining for uranium or plutonium on Earth for Martian energy could also cause environmental damage on Earth.

14.1.4 Economic factors

The research and development of nuclear reactors is extremely high due to the extreme physical conditions and constraints that must be met for nuclear reactors to produce energy. Additionally, just the cost of building a large scale reactor on Mars would cost billions of dollars for the transportation or production of materials, as well as the cost of building on Mars.

14.2 Solar

Solar energy is used in many places on Earth and is a popular source of renewable energy due to its relatively low price as well as fairly large electrical output. Solar energy is considered renewable due to its ability to sustain energy output without using a source of fuel that is limited. Solar power converts the energy carried by photons from the sun to usable electricity. However, solar power can only produce electricity during the day, meaning solar power must be used with another source of energy or stored in large batteries or capacitor banks that can supply the large energy demands at night. Additionally, the dust on Mars could cover the solar panels, making them less effective.

14.2.1 Advantages

- Lighter than nuclear power
- Less development costs
- Renewable
- Relatively cheap

14.2.2 Disadvantages

- Can be covered with Martian dust
- Only works during the day
- Requires lots of direct access to sunlight

14.2.3 Environmental factors

Solar power would have near to no environmental impact due to it being a renewable and only using the sun's energy. The only environmental impact would be the resources needed to create the solar panels which compared to radioactive waste, is not much.

14.2.4 Economic factors

The cost of making large solar infrastructure will be a lot to develop and produce. Additionally, solar can't be used by itself unless large battery banks are utilized to store energy for night, also adding to costs. This would mean that solar infrastructure by itself is not enough to power a civilization on Mars.

Part IV
Conclusion

The exploration of Mars will be essential for the development of mankind. In order to support human life on the red planet, we must find methods and sustainably gathering and producing essential resources for human life. Obtaining water, oxygen, and fuel will be necessary for any long term activities on the surface of Mars. Through the use of latest technologies, mankind will be one step closer to being an interplanetary species.

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