Economic Analysis for In-Situ Resource Utilization on Mars in Support of the Generation of Rocket Fuel and Potable Water

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The goal of the project is to determine if it is more economically viable to create rocket fuel and store it in-situ on Mars than to ship it from Earth. Generating potable water serves as a secondary objective as this process is a byproduct of the creation of rocket fuel. Our team considered the following two fuel source options: hydrogen generated through the water-gas shift reaction and methane produced utilizing the catalyzed Sabatier reaction. Ultimately, the latter was selected due to the fact that meaningful volumes of methane can be stored by liquefying the compound at -259 degrees Fahrenheit at one atmosphere, while hydrogen liquefies at the much lower value of -423 degrees Fahrenheit at one atmosphere (National Center for Biotechnical Information, 2021). Given the temperatures typical of Mars' atmosphere, this property of methane makes it easier to manage than hydrogen. Additionally, the orbits of Earth and Mars dictate the available time frame for producing enough rocket fuel for the return trip (Williams, 2015). One launch window cycle lasts approximately 26 months with each leg of the journey requiring 9 months of travel; the period of opportunity is roughly 8 months (Redd, 2017).

Equipment outside of simple machinery such as pumps, compressors, and heat exchangers that will be utilized includes electrolyzers, a catalyzed Sabatier reactor, a water desalination system, pressure swing adsorbers, dehumidifiers, and compressed liquid storage tanks to stockpile products, as illustrated in *Figure 1*. The water desalination system will refine ice crystals found underneath the Martian soil and separate them into hydrogen and oxygen via electrolyzers. This ice can be collected by humans with picks, shovels, and wheelbarrows as the crystals are located close to the surface. Different perchlorate salts can lower the triple point of water and improve the stability of water in the liquid form on Mars, but we have opted to involve water in the solid form in our process instead, as these compounds are rare on the planet (Nair & Unnikrishnan, 2020). Pressure swing adsorbers will separate carbon dioxide from other trace gases in the Martian atmosphere using molecular sieves or zeolites to remove these impurities. The catalyzed Sabatier reaction will generate the products of methane and water via the reduction of carbon dioxide by hydrogen. Blauth et al. found that methane purity and production using this reaction were optimized by incrementally lowering the heat from a high inlet temperature of about 600 degrees Celsius to drive the reaction to about 300 degrees Celsius (2021). Lastly, detailing the intricacies of providing electrical power for the rocket fuel generation process was determined to be out of the project's scope, so it was established that a nuclear reactor will provide electrical power, which will be budgeted for in the economic analysis.

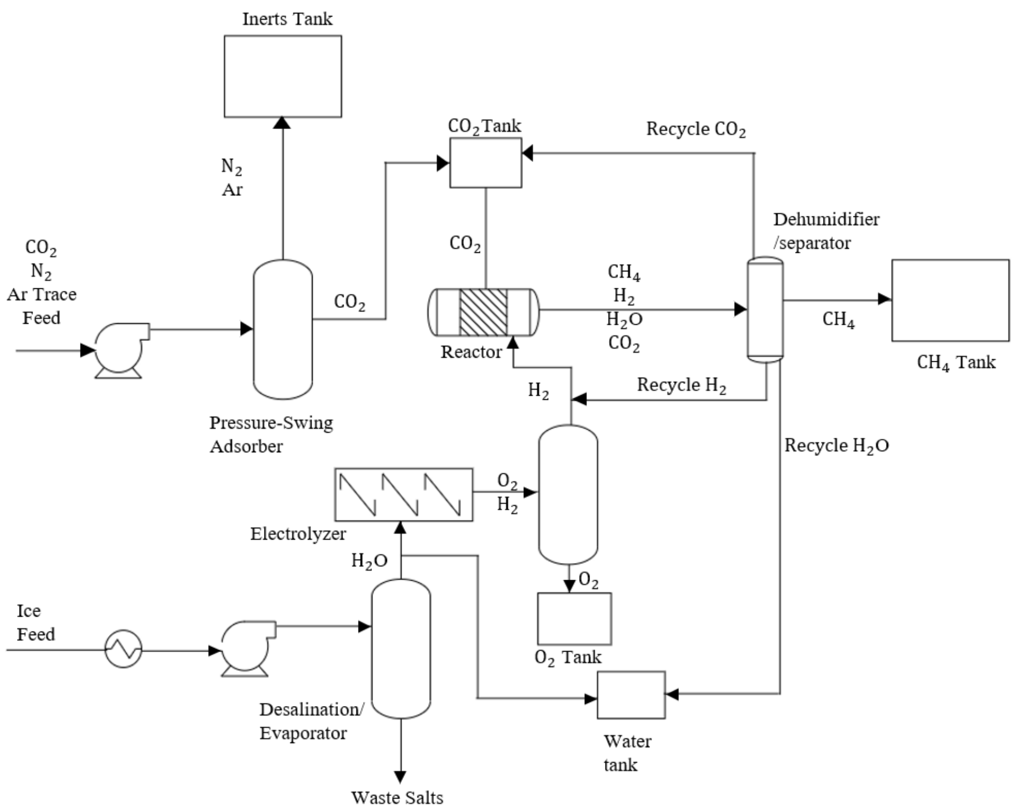

Figure 1: Process Flow Diagram for Generating Rocket Fuel and Potable Water

Relevance

Extraterrestrial exploration has been discussed for decades, but the announcement of SpaceX's Mars missions has seemingly induced greater interest lately. Recent discoveries via NASA's Mars Exploration Program have also appeared to increase the likelihood of colonization of the planet. Specifically, NASA's Perseverance rover and Ingenuity helicopter discovered rocks on Mars that suggest the presence of essential resources and water on what was once thought to be a barren planet (Neuman, 2021). The concept of space exploration on the whole is compelling because the settlement of other planets would advance humanity's understanding of the universe overall.

The existence of substantial economic incentives for industrialization of a colony on Mars makes this project interesting now. A 2013 NASA report stated that the space agency enhanced the competitiveness of, spurred innovation and growth in, and created employment opportunities in the technology and manufacturing fields (Dallas et al., 2020). Advancements in communication, internet, weather prediction, and GPS are reliant on the development of space technologies, benefiting the economy through the resultant job creation. In 2019 alone, NASA supported more than 312,000 jobs, generated $7 billion in taxes, and created $64.3 billion in total economic output (Inclán et al., 2020). These numbers probably only stand to improve due to newly invented innovations driven by the heightened competition surrounding Mars exploration.

Although progress is being made in the quest to colonize Mars, obstacles have arisen that serve as major roadblocks on the final frontier. In particular, issues regarding the economics of resource allocation and transportation to Mars have proven to be considerable. According to NASA, it costs $10,000 to send 1 pound of payload into Earth's orbit (Boen, 2008). From a safety standpoint, the transportation of these materials could also present dangerous conditions for human travel and settlement. For these reasons, extraterrestrial industrialization has become an alternative consideration. This topic relates to in-situ resource utilization, which may be preferential for facilitating such exploration in the most cost-effective manner. Neglecting finances, maximizing self-sufficiency by way of minimizing reliance on the storage and transportation of a finite amount of any resource from Earth seems favorable for such a journey. This project attempts to confirm this hypothesis by monetarily comparing the viability of material transportation versus extraterrestrial industrialization, specifically with regard to rocket fuel and potable water, to target the economic issues related to space exploration.

Logistics

In a technical sense, our team intends to utilize a combination of computational tools and prior research in order to undertake this project. Across the two semesters of CHE 4474 and CHE 4476, we will employ computational tools such as Aspen Plus and Microsoft Excel to simulate process conditions and solve complex equations for modeling a water purification and reutilization system on Mars. While the capabilities of Aspen Plus are somewhat limited for this purpose, we plan to overcome this hindrance by first carrying out calculations to determine the parameter values required to achieve membrane separation via reverse osmosis. The resultant numbers can then be applied to a separator block in Aspen Plus with contaminated water on one side and clean water on the other side, all for the purpose of simulating purification. In order to learn more about the theory behind and applications of the systems involved in the project, our team will rely on prior research, to include past capstone projects. The compiled resources will collectively be used for procuring design data and as the basis for any of our own novel computations.

Additionally, a dependence on coordinated teamwork between our four members will be paramount in facilitating the achievement of our project aims. To date, we have established a culture for keeping communication at the center of our efforts. For example, in the event that something comes up that causes a team member to be unable to complete a portion of the project by a previously determined deadline, that individual should feel comfortable alerting the others of the situation so that appropriate adaptations can be made and support can be extended. In terms of dividing the work and checking each others' contributions, our team has been convening on a weekly basis to generate ideas, discuss ongoing responsibilities, and equitably delegate impending tasks based on personal interests and skill sets. We plan to utilize this strategy for the duration of the project, but at certain intervals we will reflect on the sufficiency of the meeting frequency and decide whether it should be adjusted based upon the specific demands of present and future aspects of the project.

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