**Design of an In-Situ Fuel, Oxygen, and Potable Water Supply System on Manned Mars Missions**

(Technical Paper)

**The Role of Marketing and the Economy in the Initiation of a Paradigm Shift**

(STS Paper)

A Thesis Prospectus Submitted to the

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Bachelor of Science, School of Engineering

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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

Signature Craig Doody Date 5/6/20
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Michael Gorman, Department of Engineering and Society

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## Peer Reviews and Comments

The drafting of my prospectus involved much preparation and reviewing of the material to achieve the greatest clarity. I would like to thank all those who have provided support and feedback through this process, which I will try and acknowledge here.

Professor Michael Gorman directed me to use trading zones as my STS framework, after initially considering using Actor Network Theory. He also provided some of his expertise on paradigms and suggested that I look into Kuhn's work on paradigm shifts. He also included several comments on my draft that helped me clarify what I meant, for example considering the differences between a technical or artistic paradigm shift. He encouraged me to dig deeper and always ask why what I am saying should be considered important. I only slightly addressed his suggestion to describe how buildings meeting LEED standards should be adaptable and have the ability to add/remove different features without requiring a full reconstruction. Also, Professor Gorman also advised that addressing how the environment and economy are interconnected would add more depth to the paper.

Sabrina Stenberg provided feedback in the brainstorming stage that I should choose the idea that most aligned with our technical project.

Daniel LeDuc recommended that I listened to the podcast "The Way I Heard It" by Mike Rowe. This led me to discover the case study of Joseph McVicker rebranding Play-Doh.

## Introduction

Every year millions of students earn their undergraduate degree and are sent out to face "real life" being told that they are the future and that they will change the world. Historically speaking, it only takes an idea to instigate a paradigm shift, but what will be the difference from an idea impacting the world versus ending up on a crumpled piece of paper in the trash? Thomas Kuhn made the term "paradigm shift" a common phrase when referring to radical change; he described it as a breakdown of old ideas (Hairston, 1982). A common example would be Darwin providing scientific backing to what he proposed to be evolution (Lucas, 1985). This was met with resistance, yet his model prevailed because it was scientifically sound, and thus the paradigm shift took effect.

A paradigm is described as a set of related ideas that are generally accepted such as Newtonian physics (Bird, 2018). Therefore a shift occurs when old ideals are challenged and eventually replaced (Rodriguez-Sickert, Cosmelli, Claro, & Fuentes, 2015). Such a shift occurred when Einsteinian physics challenged Newtonian physics, or during the Renaissance when science was incorporated into art, or even the Industrial Revolution as machines decreased human labor requirements. These events were major turning points in the history of the world the propelled humanity forward in terms of knowledge and technology. This brings around the question that I would like to explore: what does it take to instigate a paradigm shift? Rodriguez-Sickert et al. (2015) explore this question and propose a model that attempts to account for a few of the complexities that push forward a new paradigm, which is why I would like to explore their model further.

For my technical topic I am working with four other undergraduates to explore how to make a sustainable Martian colony for extended period of time by In-Situ Resource Utilization (ISRU). It was the introduction of this topic that revealed to me that we have the technology to solve some of Earth's problems such as overconsumption of materials and improper disposal of waste, so I wondered why research was being poured into making a self-sustaining colony on a different planet when it would be beneficial to start on our own planet. My group's design will cover extrication and processing of the materials on Mars to provide hydrogen/oxygen fuel, oxygen to breathe, and water to drink.

As my team explores how to use the molecular compounds of the Martian regolith and atmosphere, I will be exploring how to instigate a paradigm shift in the use of materials on Earth as my STS topic. This shift is necessary because many people have the "out of sight, out of mind" mentality; therefore waste processing considerations are not receiving the attention they deserve. I will investigate how to achieve such a feat by delving into historical paradigm shifts and their causes, and determining if they were intentional or not. Based on this information, I will explore why some unintentional actions create a paradigm shift, while other world changing ideas fail to gain traction. In order to explore what role society has to play in the implementation of a paradigm shift I will be using the STS framework of trading zones to see how the economic and social impacts affect the development of ideas. Trading zones will be useful in determining what common fields play a role in the spread of information, and what causes this radical change to gain traction among society. These loci of sharing knowledge is essential to bridge the intellectual gap that forms as a result of taking the existing conditions of society for granted, and accepting them as the absolute truth (Gorman & Werhane, n.d.).

## Technical Topic

**Design of an In-Situ Fuel, Oxygen, and Potable Water Supply System on Manned Mars Missions**

*How can we design a cost-effective system on Mars to produce hydrogen/oxygen fuel for transportation to and from the planet, and provide oxygen and water to the inhabitants of a manned outpost?*

Our group's capstone advisor is Professor Anderson and the group members are Craig Doody, Michael Mace, Spencer Plutchak, Sabrina Stenberg, and Rahim Zaman, all of the Chemical Engineering Department. Our project goal is to optimize the utilization of Martian resources to provide water and oxygen to sustain a human colony, as well as produce enough hydrogen/oxygen fuel for their return trip to Earth. Design work for this project will be continued in the Spring semester with the same team.

The National Aeronautics and Space Administration (NASA), other federal space agencies, and private companies plan to send humans to Mars in the next several decades. The costs of material and equipment transportation from Earth will comprise most of the mission costs. According to a NASA report by Kleinhenz and Paz (2017), storage costs could be drastically cut with the use of In-Situ Resource Utilization (ISRU), which will utilize Martian resources for Mars base necessities. These essentials include fuel for a return trip, as well as oxygen and water for a life support system. The process must be economically viable to ensure adequate investment, the importance of which is discussed by Shishko et al. (2015).ISRU optimizes the use of materials, recycling where possible, as described by NASA (2019). Powell et al. explains NASA has researched optimal ways to provide oxygen and water for a Martian colony, as well as sufficient hydrogen to fuel a rocket for their return trip (2001). Hydrogen will

be obtained using multiple methods and stored for later use, and the Mars Oxygen ISRU Experiment (MOXIE) is the current method proposed to produce oxygen, as reported by Meyen et al. (2016). The water will be mined from the ground, either in solid or liquid form, and purified. Our proposal is to design a continuous process, utilizing available resources, to improve production output and energy efficiency. The hydrogen production will be achieved by reforming methane, collected from the regolith, and from the water-gas shift reaction. These reactions produce carbon monoxide and carbon dioxide, respectively, that can be recycled to increase hydrogen production. MOXIE will generate the oxygen necessary for the colony. Some specifications still undefined include energy sources to keep the processes running for the colony and the equipment to extract the materials from the atmosphere and regolith.

Our system consists of multiple reactor and separation units, as seen in Figure #. Reactor units will reference literature for kinetic constants, catalytic behaviors, and reactor size, using hand-calculated scaling and approximation techniques when necessary. The reactions involved follow equilibrium behavior, which has several useful models to help predict properties. Separations will be evaluated using AspenTech simulation technology. Size, duty, and cost will come from Aspen calculations, with hand calculations for initial guesses and confirmations. Aspen will also allow us to optimize energy use in the system, modelling components such as heat exchangers and turbines for energy conservation. Since we do not have means to directly test the system, the Aspen models and reactor calculations will be combined for an overall cost proposal. The costs of operation and transport of our equipment will be compared to the costs of directly transporting our products to Mars.

At the end of this project, we seek to define a process with unit operations that can produce hydrogen, oxygen, and potable water on Mars. Oxygen and water production will meet the life-support demands of 10 colonists for an indeterminate period of time, and the hydrogen and oxygen fuel will sufficiently support a return trip to Earth. Since equipment and materials will have to be transported from Earth, accurate cost estimates are integral to this project. This project will contribute to ISRU research for manned missions, and later colonies on Mars. Future research projects should include drilling designs for water extraction on the Martian surface and living spaces for the colonists.

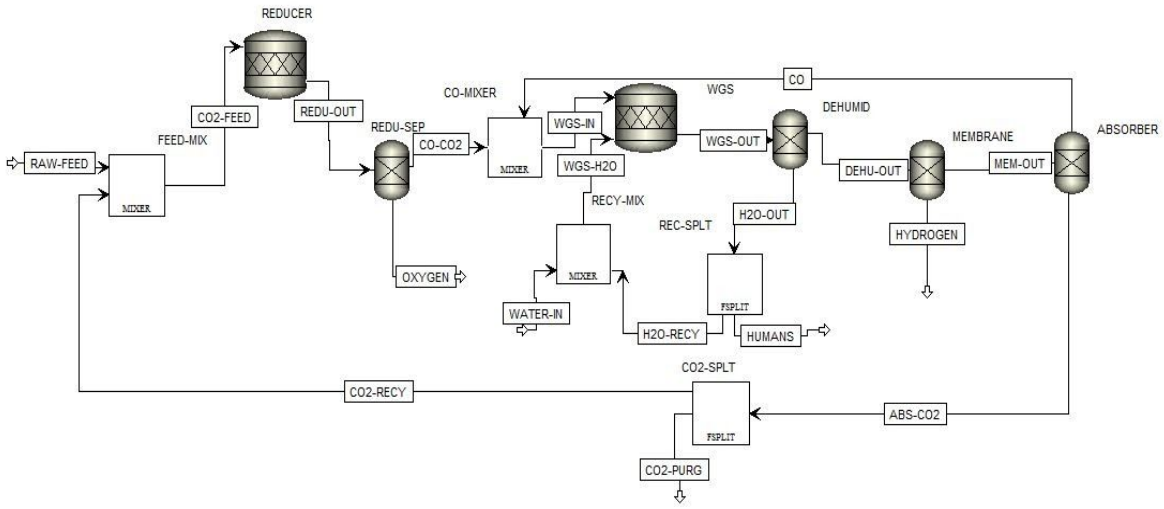


***Figure 1**: Process flow schematic including the integral operations of reactions, separations, and storage.*

## STS Topic

Trading zones play a pivotal role in a paradigm shift. The creation of an environment where information is shared allows for each aspect of a project to be understood by others with a

different area of expertise. One such example of a trading zone can be found in Hollywood moviemaking. Films are created with the intent to grasp the audience's attention, and this is achieved in more ways than the content of the film. Successful films put extensive research into developing a solid background and plot that people can relate to. Additionally, publicity can be a key factor in whether a film flops, this would spell bad news because low viewership would mean low profit. Everyone is familiar with the Disney franchise because they are experts in reaching out to the public and generally delivering a widely acclaimed film, and they have been like this since the very beginning. All factors were in place to create a paradigm shift, all that was needed was an idea, and that came in the form of the movie, Bambi, even though it was unintentional. The Bambi Factor resulted in greater sentimentality towards the preservation of wildlife and nature due to the anthropomorphizing of the forest creatures ("How 'Bambi' Hoodwinked American Environmentalists," n.d.). This is interesting because this was not intended when the movie was made, so how could a paradigm shift occur if it was unintentional? I searched for the answer in areas where a paradigm shift was forced, and therefore all factors going into it were intentional and known.

Today's world is faced with a growing problem in resource consumption and has drawn the attention of policymakers which is seen the transferal of agenda from the Millennium Development goals to the Sustainable Development Goals in 2015 (Schandl et al., 2018). One such proponent towards sustainability would be Leadership in Energy and Environmental Design (LEED) certification. LEED is the main rating system to judge how sustainable new buildings are (Akcay & Arditi, 2017). While this is a great initiative that promotes a more sustainable lifestyle, it does not make sense why civil engineers and architects went along with this, given

that many expensive adjustments would have to be made on their building for that LEED certification. The reason can be found in many cities such as the District of Columbia which have made it a requirement that all new buildings be at least LEED Silver certified ("Green Building Act of 2006 | ddoe," n.d.). However, given that it is more expensive to construct LEED certified buildings, it tends to attract a higher income community which creates a whole new set of problems that can be looked into further (Hopkins, 2019). The social implications will need to be investigated further. The implementation of LEED was a paradigm shift of necessity, this was forced upon the world and policymakers made sure it was accepted even though it may not have been economically feasible. In this case all external factors were deliberately disregarded in order for this change to take effect. However, even though factors such as the economy and the engineers opinion were rejected, the act of ignoring them meant they had to be addressed in the first place. This was an important step forward in improving the public's emphasis on sustainable projects, however sustainable solutions today may appear outdated to technology developed in the future. Some considerations when implementing green solutions on new structures should be that the construction should be able to adapt and not become outdated, this should be performed as a cost analysis for future improvements. I next want to look at a situation where instead of ignoring external factors, they were manipulated to implement a change.

Hardly anybody today would know what Kutol Products wallpaper cleaner is, but everyone knows what Play-Doh is. What do these products have in common? They are one in the same. When Joseph McVicker inherited Kutol Products Company, their most successful product was the wallpaper remover which clean the walls of soot stains that were a result of burning coal for heating purposes, but the introduction of natural gas meant the end of soot stains

and the end of the need for wallpaper cleaner. McVicker saved the company with is knowledge of marketing and the economy. Due to the pliable nature of the wallpaper cleaner, he rebranded it as molding clay to play with, which is now known as Play-Doh ("Kutol Products Company—Ohio History Central," n.d.). This simple change in name, and through some

Now a general picture of who needs to be involved in a paradigm shift seems to be forming. An idea holder, an economic expert, society as a whole, and even professionals in areas that have an external impact such as environmentalists. Each area holds different amounts of weight that will vary between projects, in the process of creating change. While LEED certifications created a paradigm shift, the environment won out over economic feasibility, but there is another case study where a paradigm shift failed to take that seems to contradict this reasoning. Why aren't road cells around today? Road cells collect the kinetic energy from cars to convert it into energy sources ("Recovering energy from traffic," 2019). We do not see these today because countries cannot handle the economic impact on converting roads, nor is there confidence that it will last through all weather conditions in addition to normal use (Symeoni, n.d.). This sheds a new light on the situation because unfortunately, the economy usually holds greater weight than environmental impact when it comes to policy making. This is ironic due to how a healthy economy can be dependent on a healthy environment. The effect of climate change on the economy is attempted to be predicted through the hedonic approach, yet theis can hardly be considered accurate because it fails to account for changes that people may implement such as using more fertilizer or even fluctuations in the stock market from exterior causes (Deschenes & Greenstone, 2004). Although a model for the future is uncertain, it is clear that a prosperous economy relies on the environment and vice versa.

The heavy impact of the economy is extremely lamentable especially since it is not looking good any time soon. Tyler Cowen refers to this period as "The Great Stagnation" which he describes has been in effect since the 1970s. Since the economic growth has slowed down, Cowen has paired this with the decline of technological growth. If society does not have the capacity for technological growth then it is unlikely that there will be a paradigm shift. I would like to research further whether a paradigm shift would improve the economy, or an improved economy would be more conducive for a paradigm shift.

Thus, we are stuck in a world brimming with technological ideas, but also one that is not accepting of them. Yet it is imperative to have a paradigm shift in the usage of materials. My capstone team has developed a solution in order for a colony on Mars to survive off of the resources present with no environmental impact, when this technology would be just as valuable if it was in use on Earth.

## Conclusion

Marketing, economy, societal opinion, and external factors such as the environment, each play respective roles in developing an idea into a worldwide phenomenon, and thus a paradigm shift occurs. These factors must be considered, whether the are being disregarded as with LEED, manipulated like with Play-Doh, or unintentionally create an effect as with Bambi. I intend to further research the necessary expertise for a trading zone to determine if a paradigm shift would occur; however the economy and environmental impacts will be determining factors in how society reacts. My capstone group intends to complete our model of the sustainable Martian colony and compute the costs, material, and energy requirements. I will finish a report that

explains how this technology will be useful on Earth as well and propose a way to make it accepted given the historical success when it comes to a paradigm shift.

## Resources


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