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

(Technical Report)

Developing a Holistic Approach to Green Energy for Energy Justice

(STS Research Paper)

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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

As engineers, we seek to solve problems both nascent and chronic. With my research, I look to examine problems in each category. For my Technical Topic research, my team and I will be designing a process to produce hydrogen, oxygen, and drinking water on the Martian surface. The process will consist of several on-site reactors, separators, and purifiers needed to produce the needed components to sustain 10 astronauts. The hydrogen will be used as fuel for the return rocket, the water will be used to sustain these astronauts on the planet, and the oxygen will be divided among the two applications. The project will be analyzed on its ability to meet human consumption and rocket operation demands, as well as the cost compared to shipment of similar quantities of material. For the STS Thesis, I will be researching the use of renewable energy as a means to help those impoverished or previously isolated from available energy opportunities. The work will consist of both looking at renewable energy's effect on poverty, as well as its effect on rural communities and homes. I will also make observations on the efficacy compared to current energy options.

Technical Topic

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. (n.d.).

ISRU optimizes the use of materials, recycling where possible, as described by NASA (Mahoney, 2017). 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.

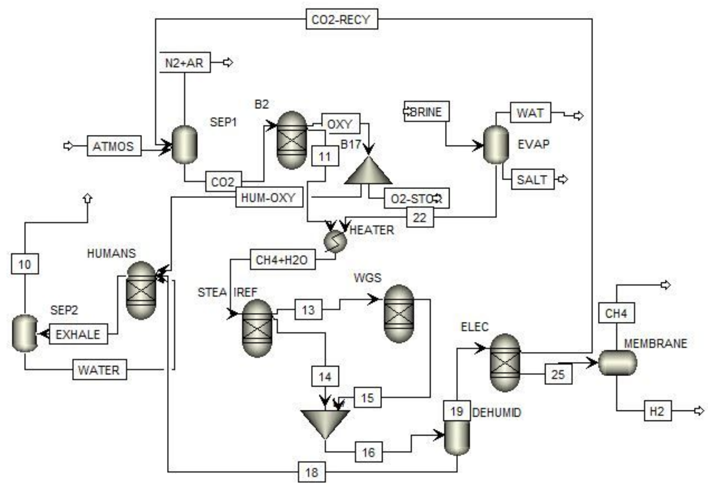

Figure 1. Process flow schematic including the integral operations of reactions, separations, and storage.

Our system consists of multiple reactor and separation units, as seen in Figure 1. 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.

STS Thesis

Introduction: Developing a Holistic Approach to Green Energy for Energy Justice

Having access to energy is a modern necessity. Energy provides opportunities, not just directly through jobs maintaining their systems, but through the ability to commute to work, keep our homes lit and warm, cook food and retrieve water, and connect to educational resources through the internet (Levey & Schuller, 2018). In fact, these opportunities can be seen as basic human rights to some nations, under Articles 13, 23, 25, and 26 of a UN agreement ("Universal Declaration of Human Rights," 2015). However, energy is not distributed evenly amongst the people of the world. The solution is energy justice, defined as providing impoverished communities with the same access to energy as more affluent regions (Jenkins, McCauley, Heffron, Stephan, & Rehner, 2016). There is, however, another issue at play: the environment. As the world edges closer to irreversible climate change, we need to be conscientious of where our energy comes from. Energy solutions need to be green for the sake of the planet. Are these two goals irreconcilable? My research seeks to answer this question by analyzing the implementation of various green energy systems to help provide much needed energy to energy-impoverished groups.

Literature Review

To analyze this issue, we can compare the poverty of nations directly to their use of green energy sources. One study by Julius McGee and Patrick Geiner found that clean energy can work against reducing poverty if incorrectly implemented, and vice versa. They found that CO_2 emissions stagnated in countries where energy inequality decreased, and emissions decreased in places of stagnant inequality. They noted that one of the biggest issues in implementation was tax incentives for energy, which only benefited those who could afford personal energy sources and burdened those connected to the grid. More holistic approaches are needed to combat this balance, especially, as the authors state, since access to energy should be a human right (McGee & Greiner, 2019).

A potential way to look at better green energy implementation is a geographical approach. There are two different approaches to the problem: prioritizing unique, available sources in the region (Organization for Economic Co-operation and Development, 2012), or optimizing common green technologies, such as wind, solar, and hydrothermal, in general regions (Brown, Nderitu, Preckel, Gotham, & Allen, 2011). In Brown et al.'s approach, they compare the pros and cons of multiple forms of renewable energy, and then compare these factors to regions that would help minimize their disadvantages and/or maximize their advantages (2011). The other approach, described by the Organization for Economic Co-operation and Development (OECD), looked at cities around the globe that chose energy diversification applicable to their city (2012). This method allowed cities to make rational choices for itself, but required each city to perform individual research into viable options; such solutions may or may not be viable elsewhere.

Framework

I will try to address the balance of green energy and energy justice through implementation based on McGee and Geiner's guidelines with additional non-economic factors. Implementation will need to be cost effective, but also targeted to make sure that underserved groups are represented in these solutions. Again, the main issue they saw was that green energy incentives were economically selective, not effectively integrating low-income groups. And, areas that saw energy justice improve relied on standard fossil fuel systems and lacked energy diversity in the approach. As suggested by Dr. Harry Powell, an effective system for isolated, impoverished regions would be localized solar systems installed communally, as opposed to connecting them to an effectively-inaccessible, coal-powered city grid (H. Powell, 2019). This falls in line with McGee and Greiner, as the approach solved both the direct need for energy while doing so in a greener way. My work will consider both economic as well as social factors when weighing whether a solution fully meets the needs of the community.

Methods

My research will follow a combination of both the OECD approach and the work of Brown et al. Green energy implementation will start with collecting grassroots and common methods, analyzing their pros, cons, and implementation potential, designating national regions of viability, then letting cities decide among the selection to meet needs effectively. Putting in a new factory may not be the optimal solution for a certain region, so localized green energy systems would be more appropriate to fix the issue. Then, with viable energy systems selected, cities will implement them to include low-income regions to achieve energy justice. Take Bangladesh as a successful example. They expanded small-scale solar works, providing direct jobs to hundreds of thousands and electricity to millions (Kyte, 2015). By directly pushing companies to invest in clean energy solutions that worked for the region, they were able to bring those communities out of energy poverty.

Discussion and Next Steps

In order to make sure energy solutions are holistic, more implementation techniques are required. I will find further examples of local and national efforts, as well as corporate efforts to implement effective systems. Plus, I will collect green energy technologies, such as the local examples listed in the OECD collection, and recommended implementation strategies that worked for similar technologies. Once all angles, options, and techniques are combined, we can then start to effectively and meaningfully address this inequality throughout society.

Bibliography

Brown, S. V., Nderitu, D. G., Preckel, P. V., Gotham, D. J., & Allen, B. W. (2011, April). *Renewable Power Opportunities for Rural Communities*. Retrieved from https://www.usda.gov/oce/reports/energy/RenewablePowerOpportunities-Final.pdf

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research & Social Science*, *11*, 174–182. https://doi.org/10.1016/j.erss.2015.10.004

Kleinhenz, J. (2017, January). *An ISRU Propellant Production System to Fully Fuel a Mars Ascent Vehicle*. Retrieved from https://ntrs.nasa.gov/search.jsp?R=20170005179

Kyte, R. (2015, August 10). World Bank: Clean energy is the solution to poverty, not coal. *The Guardian*. Retrieved from https://www.theguardian.com/sustainable-business/2015/aug/07/world-bank-clean-energy-is-the-solution-to-poverty-not-coal

Levey, T., & Schuller, S. (2018, September 17). To End Poverty, Increase Access to Energy. Retrieved October 23, 2019, from Scientific American Blog Network website: https://blogs.scientificamerican.com/observations/to-end-poverty-increase-access-to-energy/

Mahoney, E. (2017, January 23). In-Situ Resource Utilization [Text]. Retrieved September 25, 2019, from NASA website: http://www.nasa.gov/isru

McGee, J. A., & Greiner, P. T. (2019). Renewable energy injustice: The socio-environmental implications of renewable energy consumption. *Energy Research & Social Science*, *56*, 101214. https://doi.org/10.1016/j.erss.2019.05.024

Meyen, F. E., Hecht, M. H., Hoffman, J. A., & MOXIE Team. (2016, August 11). Thermodynamic model of Mars Oxygen ISRU Experiment (MOXIE) | Elsevier Enhanced Reader [Journal]. https://doi.org/10.1016/j.actaastro.2016.06.005

Organization for Economic Co-operation and Development. (2012, November 10). Linking Renewable Energy to Rural Development—OECD. Retrieved October 29, 2019, from https://www.oecd.org/regional/linkingrenewableenergytoruraldevelopment.htm

Powell, H. (2019, September 26). *STS Field Work Interviews* [In-person].

Powell, J., Maise, G., & Paniagua, J. (2001). Self-sustaining Mars colonies utilizing the North Polar Cap and the Martian atmosphere. *Acta Astronautica*, *48*(5–12), 737–765.

Shishko, R., Fradet, R., Saydam, S., Dempster, A., & Coulton, J. (n.d.). An Integrated Economics Model for ISRU in Support of a Mars Colony–Initial Status Report. In *AIAA SPACE 2015 Conference and Exposition*. https://doi.org/10.2514/6.2015-4564

Universal Declaration of Human Rights. (2015, October 6). Retrieved October 29, 2019, from https://www.un.org/en/universal-declaration-human-rights/