Paper ID #35102

Design of An Innovative Module for Mars Habitation

Mr. Edgar Reyes, University of Texas at Tyler

Edgar Reyes is an undergraduate Mechanical Engineering student at the University of Texas at Tyler. His interests include thermal fluid sciences and alternative energy systems.

Dr. Mohammad Abu Rafe Biswas, The University of Texas at Tyler

Dr. Rafe Biswas is an Associate Professor at the University of Texas at Tyler in the Department of Mechanical Engineering. His expertise and interests include process dynamics and control, fuel cell systems and thermal fluid engineering education. He teaches courses in system dynamics and control, process control, energy conversion, and thermal fluids laboratory at the Houston Engineering Center. He also has been advisor and mentor to several senior design project groups.

Dr. Andres C Garcia, The University of Texas at Tyler
Mr. Benjamin Lee Stilwell, The University of Texas at Tyler
Mr. Jongin Aaron Sithideth, The University of Texas at Tyler

Graduating Mechanical Engineering candidate from the University of Texas at Tyler with ambitious leadership and dynamic interpersonal skills. He has completed a research internship for a Fortune 1000 company, an internship for a process heating manufacturer, and managed a team of 7 solidifying work structure within the organization. His passions include continuous learning and bettering others around him. Industry of interest include aeronautics and astronautics.

Christian Puckett
Christopher Nobinger, University of Texas at Tyler

Current undergraduate

Ms. Cassandra Ellis

©American Society for Engineering Education, 2021

Session XXXX

Design of An Innovative Module for Mars Habitation

Edgar Reyes, Dr. Mohammad Abu Rafe Biswas, Dr. Andres C Garcia,
Benjamin Lee Stilwell, Jongin Aaron Sithideth,
Christian Puckett, Christopher Nobinger, Cassandra Ellis
Mechanical Engineering Department
University of Texas at Tyler

Abstract

The idea of Mars exploration has existed as a strong ambition in society since the 1960s. However, the greatest challenge to exploration would be the Martian conditions which make it impossible to sustain life through natural methods. To combat this, a base implemented will need to artificially create an Earth-like environment in which life can thrive. This base would need to include a food production system for astronauts during their time of deployment to increase the quality of life and increase chances of survival. A group of 5 undergraduate students from the University of Texas at Tyler suggest innovative methods which would allow for the implementation of an aquaponics system in Mars in order to meet the demand of continuous, sustainable, fresh food production. This work showcases how an aquaponics module could ideally be implemented, in which 75 plants and 224 fish can thrive while keeping the power consumption of the module under 10 kW.

Introduction

The National Aeronautics and Space Administration (NASA) has strong ambitions to establish the Red Planet (Mars) as the second safest planet in the solar system regarding human survival. As noted by previous assignments, one of the greatest aspects of life on Earth that astronauts seek upon arrival is that of fresh food. The greatest challenge to this would be sustaining life on the harsh environment of Mars while also making it sustainable and continuous throughout the timespan of the mission. The solution to this challenge would be to develop a module in which crew members will be fed though an aquaponics system. Aquaponics is an ecosystem for plants and fish, which can be defined as a combination of hydroponics and aquaculture[1]. Hydroponics is an expanding commercial food production system which is the art of growing plants in controlled, water-based setting[2]. Aquaculture is the cultivation, rearing and breeding of fish in order to provide food security in an efficient matter[3].The aquaponics system would create an ecosystem in which fish waste will give plants nutrients, and vegetation will filter the water for the fish. Afterwards, both the fish and vegetation could be harvested for human consumption. This creates a cycle both a beneficial and relatively low maintenance for human care. The importance of this module would be to provide a substantial increase in the quality of life for crew members on Mars. A successful module would be able to produce enough fresh food to feed crew members once a month, utilizing less than 10 kW of nuclear power.

Discussion

Copyright © 2021, American Society for Engineering Education

Fish

The idea of growing vegetables in space is not new as NASA has already noted the success of various fruit-bearing plants on board the ISS. Aquaponics is the practice of growing aquatic life alongside hydroponic fed plants in symbiosis, a common hobby for backyard enthusiasts wanting to grow produce and farm-raised fish.

The prime candidate for aquaculture is tilapia; the world's most edible farmed fish and second only to salmon and carp[4]. Dietary needs of astronauts require approximately 2700 kcal per day, one fish fillet provides approximately 110 kcal[5,6,7]. Fillet production is limited to half of the fish at a ratio of 2 lbs. of fish per 1 lb. of fillet[8].Estimated production levels over a 9-month period can yield marketable sizes of 1 lb. fish. Nine months cover the deployment phase from new hatchling to a fully reproductive fish.

Tilapia are a freshwater species that live in waters ranging from 65-94 °F with optimal temperatures between 70-91 ˚F[9,10] .As a shallow water dweller, tilapia require a minimum 3 gal. of water per lb. of weight and survivability is maintained even in poor water conditions[10,11].Tilapia are generally low maintenance and have a naturally high resistance to disease. Tilapia are omnivorous and can be placed on a full plant-based diet given the proper nutrition and space[12]. Farm raised tilapia reach spawning age within 5-7 months from hatching and are harvestable at 9 months[13,14,15]. Tilapia are mouth brooders and care for the egg clutch and fry for the first few weeks after hatching. Although some species' males care for the young, separation of males and brooding females approaching sexual maturity lowers the chance of fry and eggs being eaten by competitive males and juveniles as well as untimely reproduction.

For the fish to survive the 9-month journey, methods of transport considered are as follows multi-life stage batches, centrifuges and cryopreservation. Shipping batches at multiple phases of the life cycle handle initial concerns over production, however space requirements are greater as dictated by the adult requirements and amount of fish. In addition to requiring more volume and food, muscle and bone density health concerns for the fish arose as microgravity studies of bone break down exceeds that of new bone growth in humans[16]. Unlike astronauts, fish cannot work out up to 2 hrs. per day to compensate for this loss[17,18]. The best possible way to currently simulate gravity is via a centrifuge replicating earth's 1G. However, organisms placed within centrifuges are susceptible to motion sickness[19]. It is suggested that this effect would in turn increase the tilapia's stress levels thus weakening its natural immune response.

Cryopreservation might be the simplest way to transport and possibly avoid the perils of space travel altogether. Preserving fish eggs served as a challenge in the past due to the egg's surface area, yolk and thin cell membrane. However, studies from 2017 indicate successful freeze and thaw in zebrafish eggs with an average size of 0.028 in. and a survival rate of 40%[20]. Cryogenic technology advancements made prior to the 2030 mission should be sufficient for tilapia with egg sizes of 0.051– 0.079 in. to have a similar success rate[21]. Mars maximum survival rate of frozen eggs reaching the 1 lb. adult phase is estimated at 34% based on the survival rate of frozen eggs and hatchling survival rate for Earth-based aquaponics. Crew training or experience on the thawing process is paramount to reach the current viability goal. Initial freezing process should be outsourced to a vendor specializing in cryogenics to capitalize potential losses.

Deployment schedule for the eggs is limited to a maximum of 83 eggs thawed per month with a projected survivability of 28 passing through reproduction to reach harvestability during adulthood. A total of 1,992 eggs will be shipped for a two-year deployment of which 996 will be thawed in batches of 83 eggs per month for the first year. The other 996 eggs remain in cryostasis as part of a

Copyright © 2021, American Society for Engineering Education

contingency plan in the event a batch fails to produce the monthly hatchling requirement or tank die off. New hatchlings will be placed in a removable mesh cage in each tank and can be placed in a new tank every 2 months. The mesh cage is to serve as closer method of monitoring and protection for hatchlings placed in with larger fish. Only after the adults are harvested are the fry allowed out of the mesh cage. After two months, the hatchlings are allowed out of the mesh cage to roam the rest of the tank. Upon reaching the ninth month of fish deployment, the first tank will be evaluated for harvestable adults and a fresh deployment of hatchling will enter the mesh cage.

Monitoring by the crew and interaction is critical to the success of the long-term sustainability of fish survival. Crew will have to feed the fish daily as well as monitor the water conditions weekly. Initial feed stocks should be sent to ensure proper growth and time lapse for vegetation to mature to production levels. Fish can be removed from the tank for harvest purposes via a catch net with an extendable handle. Fish can be weighed using a fish weight scale with a clamp applied to the lower lip. Should the fish's weight not be at or above the 1 lb. mark, it should be promptly returned to the tank and continued to be fed. Any feeding beyond the 1 lb. mark should be limited to 1-2% of the fish's weight. As a reminder, gravity is not the same as Earth's and an acceptable, harvestable fish weight on Mars should be at or above .376 lb. after a 9-month grow out period. Any overabundance during harvest can be bagged, frozen and stored

Vegetables

Vegetables that can grow for the tilapia fish are a necessity because hungry tilapia may eat waste or even resort to cannibalism. To combat this, the tilapia will require food that is readily available at any given time, which can be resolved by having vegetables that are able to grow exponentially in a short amount of time or grow within the same water of the tilapia. Some examples of vegetation that commonly experience rapid growth are phytoplankton and duckweed. Phytoplankton will experience exponential growth, multiplying from one million to two million cells in a matter of seconds[22]. Duckweed is a type of vegetation that contains more nutrients for the tilapia. Duckweed will double its mass in a matter of a day or two, given that it is under optimal nutrient availability, sunlight, and water temperature[23]. Algae consistently feeds the tilapia and has the most mass of the 3 vegetations mentioned so far, however it will reach its peak a few weeks after it has grown[24].

In addition to food for the fish, food must also be supplied to the crew. It is imperative that the crew stays physically and psychologically healthy for the mission. As it is noted, travelling to Mars takes several months while in limited quarters with few options. To offset such daunting conditions, considerations were made to provide fresh vegetable options. The area needed, time required, and nutritional value of the vegetables were contributing factors in making the selection of microgreens--the most favorable option. The greens are advantageous as opposed to those grown to maturity because microgreens are easy to grow, require minimum space and provides significantly more nutritious. These vegetables are of many varieties including swiss chard a good source of vitamin K, A and C, while beets contain manganese, an excellent source for healthy bones. The microgreen selection serves multiple roles. These vegetables can be directly incorporated into the aquaponic system. The greens can provide food for the fish and crew while simultaneously growing within the aquaponics system. The USDA Animal and Plant Health Inspection Service (APHIS) typically regulates plant safety. Due to the requirements of upkeep for the vegetation, it is necessary to have the initial crew regularly tend to the plants.

Incorporating broccoli and kale within the vegetation selection accounts for members of the initial Mars base crew being vegetarian or allergic to seafood. Both broccoli and kale are high in protein and other essential vitamins. The crew members will still be able to receive the nutrients needed to

Copyright © 2021, American Society for Engineering Education

inhabit the initial Mars base without worry of inflammation or allergic reactions to food. These additions provide additional options for persons with fish allergies.

Microgreens and vegetables are to be transferred in seed form, with the seeds separated by plant type and vacuumed sealed in plastic packaging. Seeds need to be isolated to keep the batches from spreading of any disease. The packaging needs to be airtight, preventing exposure to any moisture, humidity and/or oxygen. The seeds also need to be stored in a moderately cooled area and in a dark area to prevent the chance of premature germination.

Figure 1. Seed Packaging.

Waste Management

Though current the process NASA utilizes for waste management include putting nonrecyclable organic waste in a cargo ship that burns upon re-entry through Earth's atmosphere, a portion of the waste is sent back to Earth for examination.

Waste produced by the module will be minimized by upcycling where possible in order to reduce the amount of mass returning to Earth. Regarding excrement produced through the feeding of aquaculture, this product should be dehydrated and shipped back to Earth on the return trip with all waste produced by the base. Waste acquired from the harvesting and cleaning of fish as well as inedible parts of the vegetation are to be dehydrated and ground to dust in order to be combined with the vegetation grown solely for feed production then fed back into the system as nutritional supplements for the existing fish. Waste management is crucial to the long-term success of healthy aquaculture. Upcycling harvested fish parts and inedible parts cuts down on the amount of waste returning to Earth.

Electricity

The energy consumption of the aquaponics module is a paramount factor of the success of the overall initial base because of the limited supply of energy available on Mars for the mission. Currently the mission is foreshadowing to have two 10 kW nuclear reactors. Due to NASA's two-factor safety standardization, one reactor will be passive and one will be active. These reactors will be sent prior to initial crew's arrival. If the total energy consumption of the module can be narrowed down, the implementation of the module on the initial Mars base will be more apparent. Major components of the module include the aerator, water pump, grow bed lights, tank heater.

The aeration component creates bubbles that facilitate an increase of dissolved oxygen (DO) concentration, all while removing the carbon dioxide within the water. Agitation of the water creates a greater surface area, thus improving the gas exchange between the water and air[25]. Increasing the oxygen concentration improves the breathing of the tilapia. The bubbles from the aeration also simulate cover for the fish, giving a sense of comfort and security within the closed tank environment. Tilapia can withstand DO levels below $1.669 \cdot 10^{-5}$ lb./gal, so having a constant supply of DO from the aerator and algae will aid to keep the tilapia healthy[26].

The flow dynamics of the module can be designed in various ways. The specific design will include a water pump to cycle the water within the module. The water pump component keeps the water cycling to and from various tanks. The 265 gal. tanks require a pump that will maintain a maximum flow of 400 gph, allowing the water in each tank to cycle once per hour. A constant flow within the fish tank keeps the fish moving and healthy.

Since Mars lacks the necessary rays that keep plants growing and healthy, artificial lighting within the module is required. Light is one of the aspects that support plant's respiration or photosynthesis cycles. The grow bed light components are needed to insure the growth of the microgreens and vegetables. These plants need full spectrum light to fertilize seeds, initiate flowering and nurture crop as "artificial light promotes measurable plant growth even when its color temperature varies widely from sunlight."[27]. Additional to giving the plants nutrients, heat from the grow lights will possibly heat the module. Due to the airtight design of the module, this heat will stay within the module heating the tanks to an extent. This also is an advantage and may aid in minimizing energy consumption.

The tank heater serves to keep a steady temperature for the Nile Tilapia. The tilapia should ideally be kept in water with a temperature of 70-91°F[28]. The ambient temperature on the Mars surface averages out to -81°F[29] causing the implementation of a heating system necessary to keep the fish alive. Knowing that the initial Mars base will not be made of greenhouse material, the modules HVAC system within the base will support the aquaponics module to not conform to the ambient temperatures.

Launch Rocket

Starship is the choice of rocket due to its high payload capacity and minimal launch cost and has the intentions from SpaceX to serve as a Mars launch vehicle. Rockets from Russia, China, and India were considered but none have a sufficient payload capacity either volumetrically or weight wise. SLS launch costs are excessive at around $2.5 billion, while Starship's low cost is due to the proposed use as a commercial flight to the moon, thus the projected launch cost reduction to $2 million. Starship is intended to serve as a reusable vessel for Mars and has many of the features that are from the Falcon line of rockets including upright landing.

The current plan for water transportation relies on freezing it between the external shell and internal crew quarters of the ship in order to minimize any weight shift during launch and protect crew members from radiation. Size and weight restrictions for Starship are listed on SpaceX's website. The load capacity is determined to be 100+ ton with a cargo bay volume of 38850 ft^2.

Power Consumption

Power consumption is one of the most important aspects that need to be considered. It is desired that the power consumption is less than 10 kW for the module. Some of the components that consume the most energy have been mentioned previously, and are the following: Grow lights, water pumps, aerator, and water heater. Power consumption at peak demand is listed below:

Table 1. Power Consumption of Aquaponics Module considering 21 Grow Beds and 4 Fish Tanks

	Watts	# per tank/bed	Total Tanks / Beds	Total Power in Module
Grow Lights	33	264	21	5544
Water Pump	15	1	4	60
Aerator	8.5	1	4	34
Water Heater	250	2	4	2000
			SUM (W)	7638

Currently, at peak consumption the module requires roughly 7.6 kW of power. This is assuming that all components are operating, however vegetation has a diurnal cycle that needs to be taken into consideration. By considering the diurnal cycle, we understand that the maximum lighting vegetation needs is roughly 8 hours. By breaking up the grow beds up into 3 separate sections, so only 7 grow beds are being powered at any given time, reducing the power consumed by the grow lights by a factor of 3. Afterwards, the power consumption is reduced to roughly 5 kW.

Contingencies

Large amounts of water need to be taken which will utilize excessive volume and cause weight fluctuations during lift-off. To minimize this, water will be frozen prior to launch and during the trip to Mars. By converting liquid water to solid ice, weight fluctuations during take-off will be minimal and negligible. The ice will then be melted within the Martian module and the water will be regulated at a certain temperature to begin the production of aquaculture and vegetation. Similarly, maintenance and understanding of both agriculture and aquaculture can be challenging, and an astronaut with expertise in the field would have to be sent. Plants and fish could become ill and expire if not properly treated and in time. Contingency plans require quarantine tanks and plant areas, or modularity of piping and water flow. If mechanical parts are broken, spare parts or replacements need to be readily available.

Conclusion

The environment on Mars would naturally be hostile to human survival, therefore the colonization of the Red Planet requires technology that can establish a shelter with Earth-like conditions. Besides adjusting the temperature, pressure and oxygen production, the most important aspect of human survival is that of food. The aquaponics module obliges as a unique and innovative solution to sustainable food production with the added benefit of improving the quality of life of the crew. This module should function as an Earth-like ecosystem which provides vegetation, aquatic life and human to thrive and succeed in the harsh environment of space. A successful implementation of this module will have the crop and fish yield maximized while minimizing the energy consumption and need for physical maintenance for all 26 months of deployment.

Currently, the module can sustain a continuous monthly harvest of 28 tilapia weighing 1 lb. each, allowing astronauts to be fed on a bi-weekly basis while only employing 800 gal. of water and 5 kW of power consumption. As mentioned, 1 lb. of tilapia can essentially produce 0.5 lb. of tilapia meat, which is roughly 400 calories. Now, if 168 lb. of tilapia meat are harvested on a yearly basis, and that the average astronaut calorie intake per meal is 900 calories, this module would be able to produce 150 meals every year from tilapia alone. This calculation does not consider the vegetation that would be harvested, nor any other ingredients such as seasoning or condiments that would add to the calorie intake for the crew. However, the greatest aspect of this module is that this would greatly improve the quality of life for astronauts. Many astronauts that have returned from deployments have reported that the greatest aspect missed of Earth is the fresh food, such as vegetation. The aquaponics module takes fresh food a step further by providing both vegetation and aquaculture to a crew that would not otherwise obtain it for a timespan of over 4 years.

References

1. United States Department of Agriculture, "Aquaponics," [Online]. Available: https://www.nal.usda.gov/afsic/aquaponics. [Accessed 21 10 2020].
2. United States Department of Agriculture, "Hydroponics," [Online]. Available: https://www.nal.usda.gov/afsic/hydroponics. [Accessed 21 10 2020].
3. National Oceanic and Atmospheric Administration, "Aquaculture," [Online]. Available: https://www.fisheries.noaa.gov/topic/aquaculture. [Accessed 21 10 20].
4. R. Mungkung, J. Aubin, T. H. Prihad, J. Slembrouck, H. M. G. vanderWerf and M. Legendre, "Life Cycle Assessment for environmentally sustainable aquaculture management: a case study of combined aquaculture systems for carp and tilapia," Journal of Cleaner Production, vol. 57, pp. 249-256, 2013.
5. J. Cai, X. Zhou, X. Yan, D. Lucentea and C. Laganaa, "Top 10 species groups in global aquaculture 2017," 2017. [Online]. Available: http://www.fao.org/3/ca5224en/ca5224en.pdf. [Accessed October 2020].
6. J. M. Gonzales and P. B. Brown, "Nile tilapia Oreochromis niloticus as a food source in advanced life support systems: Initial considerations," Advances in Space Research, vol. 38, no. 6, pp. 1132-1137, 2006.
7. F. Wild, "Eating in Space," National Aeronautics and Space Administration, 26 November 2019. [Online]. Available: https://www.nasa.gov/audience/foreducators/stem-on-station/ditl_eating. [Accessed October 2020].
8. K. Mjoun, K. Rosentrater and M. Brown, "TILAPIA: Environmental Biology and Nutritional Requirements," South Dakota State University, Brookings, 2010.
9. B. Gjerde, S. B. Mengistu, J. Odegard and H. Johansen, "Quantitative genetics of body weight, fillet weight and fillet yield in Nile tilapia (Oreochromis niloticus)," April 2012. [Online]. Available: https://www.researchgate.net/publication/256917146_Quantitative_genetics_of_body_weight_fillet_weight_and_fillet_yield_in_Nile_tilapia_Oreochromis_niloticus. [Accessed October 2020].
10. A. M. El-Sayed, A. El-Ghobashy and M. Al-Amoudi, "Effects of pond depth and water temperature on the growth, mortality and body composition of Nile tilapia, Oreochromis niloticus (L.)," 28 June 2008. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1365-2109.1996.00776.x. [Accessed October 2020].
11. F. Kapute, J. Valeta, J. Likongwe, J. Kang'ombe, J. Nagoli and D. Mbamba, "Growth performance of three tilapia fish species raised at varied pond sizes and water depths," International Journal of Fisheries and Aquaculture, vol. 8, pp. 81-86, 2016.
12. A.-F. M. El-Sayed and S. Teshima, "Protein and energy requirements of Nile tilapia, Oreochromis niloticus, fry," Acquaculture, vol. 103, no. 1, pp. 55-63, 1992.
13. J. S. Abucay, H. M. T. Balderama and E. A. Lopez, "GROWTH PERFORMANCE OF NILE TILAPIA (Oreochromis niloticus L.) SUBJECTED TO DELAYED STOCKING AND FEEDING," [Online]. Available: https://cals.arizona.edu/azaqua/ista/ista6/ista6web/pdf/599.pdf. [Accessed October 2020].
14. M. Abdel-Tawwab, M. H. Ahmad, Y. A. E. Khattab and A. M. E. Shalaby, "Effect of dietary protein level, initial body weight, and their interaction on the growth, feed utilization, and physiological alterations of Nile tilapia, Oreochromis niloticus (L.)," Aquaculture, vol. 298, no. 3-4, pp. 267-274, 2010.
15. Tilapia.ws, "Growth rate in tilapia," https://www.tilapia.ws/, 2016. [Online]. Available: https://www.tilapia.ws/growthrate.php. [Accessed October 2020].
16. K. J. Hackney, J. M. Scott, A. M. Hanson, K. L. English, M. E. Downs and L. L. Ploutz-Snyder, "The Astronaut-Athlete Optimizing Human Performance in Space," The Journal of Strength & Conditioning Research, vol. 29, no. 12, pp. 3531-3545, 2015.
17. S. May, "Exercising in Space," National Aeronautics and Space Administration, 24 March 2020. [Online]. Available: https://www.nasa.gov/audience/foreducators/stem-on-station/ditl_exercising. [Accessed October 2020].
18. J. A. Loehr, S. M. C. Lee, K. L. English, J. Sibonga, S. M. Smith, B. A. Spiering and R. D. Hagan, "Musculoskeletal Adaptations to Training with the Advanced Resistive Exercise Device," [Online]. Available: https://d1wqtxts1xzle7.cloudfront.net/43434959/Musculoskeletal_adaptations_to_training_20160306-9610-sor4wt.pdf?1457307609=&response-content-disposition=inline%3B+filename%3DMusculoskeletal_adaptations_to_training.pdf&Expires=1603212806&Signature=fqUQ6jK1. [Accessed October 2020].
19. R. Hilbig, R. H. Anken, A. Bauerle and R. H, "Susceptibility to motion sickness in fish: a parabolic aircraft flight study.," Journal of Gravitational Physiology : a Journal of the International Society for Gravitational Physiology, vol. 9, no. 1, pp. 29-30, 2002.

20. M. Guan, D. M. Rawson and T. Zhang, "Cryopreservation of zebrafish (Danio rerio) oocytes using improved controlled slow cooling protocols," 20 March 2008. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/18433743/. [Accessed October 2020].
21. S. Martínez-Páramo, Á. Horváth, C. Labbé, T. Zhang, V. Robles, P. Herráez, M. Suquet, S. Adams, A. Viveiros, T. Tiersch and E. Cabritaa, "Cryobanking of aquatic species," 1 April 2017. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5737826/. [Accessed October 2020].
22. "Phyto Plankton : What Does it Need to Thrive?," [Online]. Available: https://www.nps.gov/glba/learn/education/upload/me_activity2_handout1.pdf. [Accessed 16 10 2020].
23. R. A. Leng, J. H. Stambolie and R. Bell, "Duckweed - a potential high-protein feed resource for domestic animals and fish.," Livestock Research for Rural Development, vol. 7, no. 1, 1995.
24. O. S. University, "Growing Algae for Fuel - Bioenergy Education Initiative," [Online]. Available: https://agsci.oregonstate.edu/sites/agscid7/files/bioenergy/education/algae_final_interactive.pdf. [Accessed 16 10 2020].
25. D. A. Pattillo, "An Overview of Aquaponic," North Central Regional Aquaculture Center, 2014.
26. "Mwea Aquafish Farm," MAF, [Online]. Available: https://mweafish.com/aquaculture-articles/25-temperature-and-low-dissolved-oxygen-tolerances-for-tilapia.html#:~:text=Tilapia%20are%20able%20to%20survive,no%20fish%20mortality%20in%20tilapia. [Accessed 16 October 2020].
27. M. M. Braunstein, "Indoor grower's Guide to Gourmet Greens," Microgreen Garden, [Online]. Available: https://www.microgreengarden.com/light. [Accessed 14 October 2020].
28. "Farming Tilapia in Colder Areas," Tilapia, 2016. [Online]. Available: https://www.tilapia.ws/coldareas.php. [Accessed 15 October 2020].
29. "All About Mars," NASA Science, 2020. [Online]. Available: https://mars.nasa.gov/all-about-mars/facts/. [Accessed 08 10 2020].

EDGAR REYES
Edgar Reyes is an undergraduate Mechanical Engineering student at the University of Texas at Tyler. His interests include thermal fluid sciences and alternative energy systems.

DR. MOHAMMAD ABU RAFE BISWAS
Dr. Rafe Biswas is an Associate Professor at the University of Texas at Tyler in the Department of Mechanical Engineering. His expertise and interests include process dynamics and control, fuel cell systems and thermal fluid engineering education. He teaches courses in system dynamics and control, process control, energy conversion, and thermal fluids laboratory at the Houston Engineering Center. He also has been advisor and mentor to several senior design project groups.

DR. ANDRES C GARCIA

BENJAMIN LEE STILWELL

JONGIN AARON SITHIDETH
Graduating Mechanical Engineering candidate from the University of Texas at Tyler with ambitious leadership and dynamic interpersonal skills. He has completed a research internship for a Fortune 1000 company, an internship for a process heating manufacturer, and managed a team of 7 solidifying work structure within the organization. His passions include continuous learning and bettering others around him. Industry of interest include aeronautics and astronautics.

CHRISTIAN PUCKETT

CHRISTOPHER NOBINGER

CASSANDRA ELLIS