Project Definition Document (PDD)

Approvals

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Team Members

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Problem Or Need

The possibilities for innovation in the Cislunar environment are endless in the coming generations. In order to fulfill the ambitions envisioned by all sectors of space commerce, an infrastructure to serve these missions is vital. The availability of resources in Cislunar space can serve to satisfy needs such as transportation, energy, and sustainability. Extracting, processing, storing, and utilizing these resources is a massive challenge. Once these resources outside of Earth can be obtained, they can be used to provide beneficial impacts on launch costs and mission sustainability.

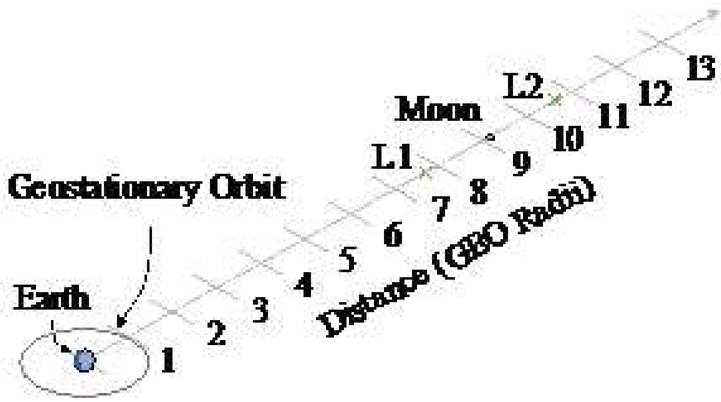

Fig. 1 Field of Application: Cislunar Space

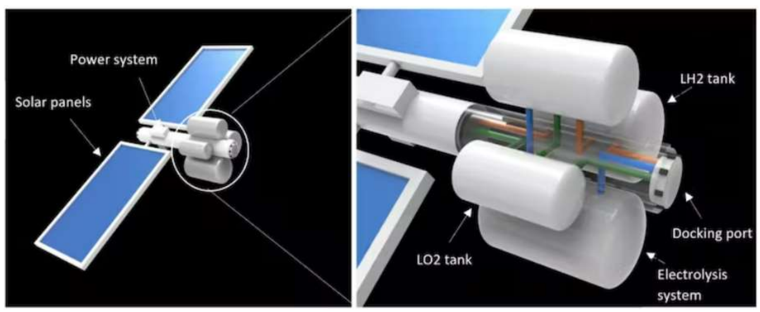

Fig. 2 Artist Rendition of Resource Depot

Previous Work

In 1966 the Outer Space Treaty set basic standards for international space law, which includes how "outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupations, or by any other means." [1]. Despite how this may serve as an obstacle to space resourcing and mining, countries including Luxembourg, Israel, and the United States have been able to do so by solely claiming resources derived from the Moon. [2] Luxembourg launched the SpaceResources.Lu Initiative in 2016, which initialized a "unique legal, regulatory, and business environment enabling private investors and companies to explore and use space resources." [3] In order to foster peace and transparency between nations, NASA founded the Artemis Accords in 2020 to create a framework for civil space exploration and use. So far the Accords have been signed by 21 countries and set a precedent to "extract and utilize resources on the Moon, Mars, and asteroids." [4] These Accords have been met with some push back from countries who have a stricter view of the Outer Space Treaty, so this is a concern to keep in mind for The Ice Box objective.

The Lunar IceCube nanosatellite, Lunar Flashlight, and Lunar InfraRed Imaging cubesat on Artemis 1 will study and map ice deposits on the Moon. With regards to bodies of water NASA has funded Small, Innovative Missions for Planetary Exploration (SIMPLEx). This includes LunaH-Map and Lunar Trailblazer, with will detect and map water on the lunar surface. In consideration of lunar long-term sustainability, the Israeli company Helios is looking to focus on resourcing and mining equipment with Lunar Extractor-1. [5]

Specific Objectives

This project is a multi-objective design with three high-level objectives in mind. The first objective is to design for fuel mining, production, and storage logistics and services. The second objective is to design for space-based power logistics and services. The final objective is to account for return on investment in the design. There are two levels that will demonstrate success for this project:

Level 1	Mission sustainability by reducing weight and thereby reducing launch cost
Level 2	Power infrastructure on or near the moon using resources obtained

Level 1 defines the minimum to consider this project a success. The overall goal of this project is to reduce the cost of launching missions to Cislunar space. This can be done in a number of ways, however, the focus of this project is to reduce the launch cost by obtaining ice from the Moon's surface. This ice can be used in a number of ways to provide sustainability, such as fuel, water, and oxygen. Level 2 elaborates on this concept by attempting to provide more detail to what the project might accomplish. Beyond just reducing cost, the team would like to power infrastructure on or near the moon using the resources obtained in level 1.

The team will demonstrate success by providing a version-controlled python code that generates an analysis and result of the design in the trade space. Additionally, the team will develop hardware that represents a high risk aspect of the design to investigate. A model will be provided to assess return on investment. Finally, an overview of the national and international policy involving Cislunar space will be created.

High Level Functional Requirements

To achieve our mission we will break our requirements into 4 phases of high level functional requirements to enable water based infrastructure. Phase 1 will involve excavating the ice. To accomplish this we will have to develop a method to collect the ice off the edges and bottom of craters on the Moon's poles. Therefore, the first high level functional requirement will be to design an apparatus enabling the collection and hauling of ice out of a crater, while operating in lunar gravity. Once the ice is above the crater it will have to be transported to a processing plant which brings us to phase 2. In this phase, the excavated ice will need to be made into an easy to transport state and brought to high interest locations where it can be utilized. This will involve either transporting ice cores or melting the ice into containers in order to store more product. Similar to the gas industry on Earth, water will need to be moved to where it is needed for human operation and in a easy package to enable efficient operations. Phase 3 involves processing and storing the ice. The processing will be done two ways. The first is to purify the water from any contaminates for human consumption as well as hydroponics or other common water needs. The second is to break apart the water into other useful products using electrolysis. This method breaks water into hydrogen and oxygen which can be used for fuel or life support for human continuity. Once processed, the separate rocket fuel components, drinkable water, and life support will be packaged in an easily usable and saleable fashion to help return on investment and to readily supply wherever need be. Lastly, phase 4 will involve space policy. As noted in Previous Work, policy in space is of interest to many nations and can be influential to all countries who look to increase their footprint in space. So it is essential to ensure that The Ice Box can not only comply with the sensitive legislation, but take advantage of the potentially large customer base in a meaningful way. Depending on how ownership will be claimed over these resources, the policies that will be developed aim to allow any entity to purchase product once it has been produced, and whoever initially claims and collects from a resource location will have rights to it. This policy will operate to ensure no conflicts arise due to this limited resource. Furthermore, the fourth high level functional requirement will include an agreement of policy that companies and countries have to sign in order to ensure peace.

Critical Project Elements

CPE	Description
	Technical
T1: Mining System	This is one of the highest risk and most important parts of this project, as we will need to acquire the resources in order to do anything with them. Mining on the moon is going to be a great challenge, and a large part of our design efforts will be spent looking into the best way to mine on the moon.
T2: Transportation System	Getting the resources from the mining site to our processing site is another fundamental piece of our infrastructure. For this we will need to design a methodology of transporting ice out from within a crater, and bring it to the processing facility.
T3: Processing System	With the raw material in hand, we must now figure out a way to turn the raw materials into usable water, oxygen, fuel, and other useful compounds. Doing this will require processes like electrolysis to convert the ice into a usable material. Defining these processes and how they are performed will be central to the success of this element.
T4: Storage	A critical element of a continuous and reliable fuel, water, and oxygen resource is storage. Determining the most energy, space, and cost efficient way of storing the mined water will require further research and testing. From this stage, we hope to determine the ideal phase, container, and stage in processing in which to store the mined water.
T5: Providing	A critical aspect of getting fuel and oxygen from mined ice is being able to reliably and cost effectively provide said goods. We face two key challenges in providing the post-processed water: transporting oxygen, rocket fuel, and water to other areas of the moon and transporting goods from the surface to orbit. These challenges require study into the balance between reliable, cheap transportation and effective, reusable storage as well as research into a point at which an in-orbit trade off of goods could occur.
	Logistical
L1: Transportation & Arranging of initial infrastructure	In order to design and execute a multistage mining, processing, and transporting operation, a method of bringing infrastructure to the moon or near orbit must be planned. This may involve building off of previously accomplished moon missions or looking in to novel, non-field tested ideas being currently researched.
	Financial
F1: Cost of a Kg to the moon	In order to achieve our goal of reducing overall cost of resources in cislunar space, understanding how much it costs to get a Kg of mass to the moon now, as well as estimating the cost of a Kg for our system, will be the primary financial driver for this mission.

Sub-System Breakdown and Interdependencies

Sub-System	Description
Excavation	An excavation sub-system needs to reach and mine ice deposits at the moon's poles in very treacherous conditions. This sub-system could use machines, humans, or a mix of both to extract ice from the extremely dark craters at the poles of the moon.
Power	A power sub-system needs to provide power to any machines and equipment required to mine, transport, process, and store the ice deposits on the lunar surface.
Water Processing	A water processing sub-system would need to take in mined ice from the moon's poles and convert it to a form that can be utilized to support missions. The ice could be converted to hydrogen to be utilized as fuel and to water and oxygen to sustain life support for human mission.
Communications	A comms sub-system is essential so all elements of the mission can be connected throughout the duration of the mission so they can interact appropriately. Data from the excavation, transit, storage, and processing systems will be sent back and forth so separate systems can execute appropriate actions throughout the mission.
Structures	All hardware and machines must be designed to handle the harsh conditions of mining, travelling, and storing on the lunar surface.
Policy	A policy system is needed to make sure the mission follows all international space policies while also maximizing the benefits of the mission.

Team Skills and Interests

Team Member	**Skills/Interests**	**CPE**
Lewis Bittner	Fusion360, SOLIDWORKS, MatLab, Python, welding, manufacturing, overall system design and integration	T1, T2, T3, T4, T5
Amir Tillis	SOLIDWORKs, Matlab, Prototyping, Manufacturing, Communication/Leadership, Customer Support/Interaction	All
Fabrizio Roberts	Matlab, Python, C/C++, C#, Electronics, Robotics/Autonomous Systems, Thermodynamics/Chemistry	T1, T2, T3, T4, T5
Collin Hayes	Python, C++, Matlab, Arduino, Data Science, Simulation and Modeling, Git, Electronics	T1, T2, T3, T5, L1
Andrew Sapuppo	MATLAB, Quantitative/ Qualitative Research, FEM Simulations, Propulsion Systems, Presentations/Public Speaking	T1, T2, T5
Reina Krumvieda	SOLIDWORKS, Git, Unix/Linux, Python, C++, Matlab, IDL, HTML, Satellite Mission Operations	T1, T2, L1
Alayna Lauffer	Matlab, soldering, Quantitative/Qualitative Research, Presentations/Public Speaking, Customer Support/Interaction, Test Engineering experience	T3, T4, T5, F1
Willy Gettinger	3D Printing, Arduino, Multisim, Testing hardware, Research, MATLAB, Python, Excel, Customer Outreach	T3, T4, T5, L1
Zachary Reichenbach	SOLIDWORKS, ANSYS, Arduino, MATLAB, Python, Microsoft Suite, Electronics, Thermodynamics, structural analysis and construction	All

Resources

Critical Project Elements	Resource/Source
T1: Mining System	Mining conditions on the moon are very different from earth, including factors like dust, gravity and quite a few other variables. Further info on conditions for design are required.
T2: Transportation System	Locations of interest for consumer needs are not well understood. Outside documentation or expertise is required.
T3: Processing System	Hydrolysis and some of the general procedures of product safety and production might be considered high risk and need to be tested. Possibly requiring specialized machinery and more outside expertise to fully develop a working and applicable understanding for the best implementation.
T4: Storage	More research and work will be required to provide products in the proper vessels for distribution and the most effective storage. Outside expertise would help to develop and understand the storage problem.
T5: Providing	Understanding the current operations of other lunar missions would guide our plan for providing supply in the right places. Similar in scope to the issues with transportation, additional outside expertise would aid work efforts.

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