Project Khepri:
Asteroid Mining Project

Final Business Report

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ABSTRACT

The business plan for the Khepri Project is to use the water mined from Bennu and convert it into fuel, then sell it at an orbital gas station.

After the research was conducted, it appears that this project is financially feasible and realistic while considering a number of assumptions due to the levels of uncertainty in this field as well as the financial and time restraints of this research project.

One major assumption made during the duration of this project is that the space economy will continue to expand and grow at a similar rate as it is currently. Additionally, we assume that the market most similar to that of Bennu's will be the Lunar market, however they are not identical. Bennu's High Earth Orbit market will include more space missions both private and public as well as permanent space stations and bases such as those planned in NASA's Artemis Program. This assumption goes hand in hand with the belief that there will be an active and growing customer base in space looking to purchase fuel.

For Bennu there are several options that have a potential to be profitable by selling propellant and water:

- Sell propellant near the Moon (lunar orbit "gas station")
- Sell propellant near the Earth (High Earth orbit "gas station", selling to spaceships and space hotels/stations)
- Sell propellant near Mars (for future NASA resupply missions and other missions to Mars)
- Large contracts with a few companies
- Smaller contracts with many companies

After extended analyses, it was determined that High Earth Orbit / Cis-Lunar gas station is the most profitable solution. This strategy allows us to sell fuel at the cost determined by the Delta V and current fuel prices on Earth, allowing high flexibility. Additionally, the sales can be performed to both small and big players as this station will be directly accessible to all spacecraft leaving and returning. Proximity to Earth also helps to maintain technological superiority of the station as well as ensure safety.
Moreover, collaboration between private and public investors will ensure cash flows as well as optimal legal outcomes, getting the greatest benefits from each sector of investment while minimizing the downsides.

In regards to risk the majority of them can be mitigated through looking at the growing pains new industries experience such as the lunar and cannabis markets which have grown and faltered. With time, more and more regulations will be established stabilizing the market and increasing the attractiveness of the sector for private investors.

As a result, mining Bennu has a high potential not only for profit from this project, but also to be the safe choice step into the currently non-existent space mining industry. It is only a question of time when this sector will become well established, and Bennu possess essential resources –mainly water to be used as propellant - that are finite on Earth. Moreover, the risks

associated with this project are similar to any new sector regardless of whether it is on Earth or not. With collaboration between public and private sectors, the exploration and exploitation of Bennu will be the first step into this industry with a highly rewarding competitive advantage for any nation or organization that is willing to take it.

Contents

LIST OF ABBREVIATIONS:

Abbreviation	Full Description
CMMP	Canadian Minerals and Metals Plan
COPUOS	Committee on the Peaceful Uses of Outer Space
CSA	Canadian Space Agency
ICJ	International Court of Justice
IISL	International Institute of Space Law
ISA	International Seabed Authority
LSC	Legal Subcommittee
MAC	Mining Association of Canada
OST	Outer Space Treaty
SDG	Sustainable Development Goals
SPACE	Spurring Private Aerospace Competitiveness and Entrepreneurship Act
SRU	Space Resource Utilization
STSC	Scientific and Technical Subcommittee
TSM	Towards Sustainable Mining
UAE	United Arab Emirates
UN	United Nations
UNGA	United Nations General Assembly
UNCLOS	United Nations Convention on the Law of the Sea

CHAPTER 1: BACKGROUND OF ASTEROID BENNU

Bennu was discovered on 11 September 1999 during a Near-Earth asteroid survey by the Lincoln Near- Earth Asteroid Research (LINEAR). The asteroid was given the provisional designation 1999 RQ36 and classified as a near-Earth asteroid. Bennu was observed extensively by the Arecibo Observatory and the Goldstone Deep Space Network using radar imaging as Bennu closely approached Earth on 23 September 1999.Bennu has a roughly spheroidal shape, resembling a spinning top. Bennu's axis of rotation is tilted 178degrees to its orbit; the direction of rotation about its axis is retrograde with respect to its orbit. While the initial ground based radar observations indicated that Bennu had a fairly smooth shape with one prominent 10–20m boulder on its surface, high resolution data obtained by OSIRIS-REx revealed that the surface is much rougher with more than 200 boulders larger than 10 m on the surface, the largest of which is 58 m across. The boulders contain veins of high albedo carbonate minerals believed to have formed prior to the formation of the asteroid.

CHAPTER 2: ASSUMPTIONS

The following assumptions were made in making this assessment.

- Political field will remain unchanged on a major scale such as conflicts that would highly affect resources, markets, as well as countries' strategies for budgets.
- Space economy will continue to expand and grow at a level similar to current rates.
- 30% ROI is achievable for this project as the Falcon 9 has the potential to reach a 27% ROI and it is a similar service in a similar market.
- The lunar market is the closest prototype for Bennu market.
- High Earth Orbit market will include more space missions both private and public as well as permanent space stations and bases

CHAPTER 3: MARKET ANALYSIS

Since the Bennu project is a pioneer in a new & developing market, market analysis is based on the Lunar market, which is still expanding, but already has several players such as the USA, China, and Japan.

However, it is important to note that the lunar and Bennu markets are not identical.

Differences:

- Size of bodies and orbits
- Radius of the Moon is 1,737.4 km while Bennu's is 262.5 m. This difference simplifies analysis and calculations of many factors such as natural resources potential. The greatest benefit is time and efficiency. Additionally, while for now it is estimated by NASA that Bennu is around 200 million miles away from the Earth, it will get within

125,000 miles which is almost halfway between the Moon and the Earth. It gives additional opportunity since resources needed for transport will decrease, however, it is important to note that space race is still an ongoing trend.

- An Earth orbit would address the market for all of the outgoing infrastructure
- For example, a shipment to a lunar base on the moon is a one-way trip. There are also space hotels being envisioned that could make use of the water that can be extracted from Bennu. Also for Earth, Bennu could be used for other missions (e.g. to Mars).

CHAPTER 4: MARKET TRENDS

The following trends were considered.

International Playground

Currently in the Lunar market, the biggest player is the USA, followed by China and Japan, as well as the rest of the world. Since the USA was an active player from the beginning, and with the collapse of the Soviet Union, they remained a leader with Moon exploration. As a result, they are the country with a competitive advantage, and it is why primacy is crucial for long-lasting benefit. However, political factors such as alliances may heavily affect collaborations.

Shift from Public to Combination with Private.

To begin with, space missions tend to rely on government investment at the beginning, and slowly balance out with the private sector. Generally, for space missions the exploration starts with orbital missions, and then moves to actual space operations. This is due to longer time periods for returns, which is highly suitable for entities such as banks and governments. It comes from the different values of each player which is discussed in the Funding and Capital section in greater detail. This trend is expected to stay with Bennu, and it has proven to be valid with the lunar market and as for now, influential companies such as Toyota, Caterpillar and JAXA announced partnership with space agencies. Furthermore, according to the PwC Lunar market assessment, this tendency is expected to grow from slightly more than 10% to above 50% in two decades. Some sectors that are going to be present in the Moon are Mining, Construction, Medicine, Agriculture, Robotics, Experiments, Energy, and Communications.

Non-Space Companies Involvement

Coming from the previous trend, companies that are not associated with the space industry are also looking to benefit from exploration, especially since many initiatives are supported by different governments. They tend to start with outsourcing from the government, and then grow into proper collaborations and projects. For example, Rio Tinto joined forces with ASA in order to utilize their mining technologies on the Moon. In the same sector, Woodside Energy agreed on a technology transfer between oil & gas, and space industries.

CHAPTER 5: RISK EVALUATION

Challenge	Probability	Impact	Mitigation
Budget Uncertainty **Unforeseen costs due to developing a new industry.**	4	3	**Creating and signing partnerships which legally protect the project.** **Mitigated by looking at the challenges in other new industries.**
Technological Unpredictability	4	3	**Keeping an eye on new technologies and discoveries in order to rapidly adapt to changing environment.** **Training staff in new and existing technologies, developing new technologies as required.**
Human Resources Inconsistency	4	2	**Since this project is long-term orientated, it may be challenging to hold the same resources from the beginning to the end.** **It is crucial to specify contracts and have a healthy work environment to keep turnover to a minimum.**
Knowledge Management	3	3	**Similar to HR inconsistency, stakeholders possess knowledge which may be sensitive in nature.** **In order to mitigate, non-disclosure agreements and proper management of access (ex. central repository) and ownership should be implemented. Additionally, document management tools such as OpenText can be useful and the creation of a knowledge retention management team.**
Investors Satisfaction	3	4	**Investors expect proper returns and management, and as mentioned before they may encounter conflicting interests (between the government and private sectors).** **Dissatisfaction prevention includes proper communication between parties as well as flexibility and clear terms of partnerships.**
Customers Satisfaction	3	3	**While mining is one of the Bennu mission's purposes, it is not guaranteed to extract the same quality of resources as predicted.**
			The best way to ensure satisfaction is sending a test mission which will provide a sample of raw materials giving a better idea of the product.
Project Change Management	3	4	**Due to the nature of the sector, changes tend to appear at any stages, and a key to success is adaptability to new conditions. This challenge focuses on this project rather than the new industry.** **AGILE Management will be the best way to maximize benefits and minimize documentation. It will allow to record working strategies and briefly elaborate on dysfunctional management methods.**
Environmental Challenges	1	1	**The environmental impact of this mission is minimal and potentially negative in the long run. While there will be some emissions and pollution from the creation and launch of our craft, by harvesting water in space and using it for fuel it preserves Earth's water supply.** **Additionally, there is a separation between the environment on Earth and in space as whole, a team should be assigned to work on the challenges faced in both environments to allow for the mission to operate withing legal bounds set by governments.**
Competition	5	2	**This risk is most likely to appear after initial steps since this market is emerging. However, it is almost certain that new players will enter new market. Nevertheless, with a competitive advantage as pioneers, only the effectiveness of the project will be threatened.**

Demand Unreliability	4	3	**With new methods of natural resource extraction affecting worldwide supply, demand will react.** **The best way to mitigate this threat is to control the mining output to protect prices on the market.** **Additionally, by looking at the challenges in other new industries, in particular cannabis, it is clear that early players receive rewarding compensations.** **However, the whole industry has challenges with supply management as well as licensing. With new players in the market, it is a high possibility that demand for Bennu's resources will be too high and once resources reach the Earth there should be technology available to receive them.** **Moreover, as a new player, it is crucial to focus on a strategy that preserves the value of these resources. It will allow not only save the pioneering group's benefits, but also extend them.**
Legal changeability	**5**	**3**	**Lack of regulations in this new market is one of the main concerns of the private sector. Similar to the Lunar market, it will require some time to develop any multilateral diplomacy and regulations.** **Recently, a legal group has been created which will work on this field for 5 years with the possibility of an extension.** **However, it is a very profitable niche from which everyone will try to benefit, and regulations will be created in a matter of time.**

Probability ranked 1-5

5	**80%**	**Almost certain**
4	60%	**Likely**
3	40%	**Possible**
2	20%	**Unlikely but could**
1	Less than 20%	**Rare**

Impact ranked 1-5

5	**Catastrophic Threat**	**Would kill the project**
4	Major Threat	**Threaten survival of project's scope**
3	Moderate Threat	**Significant impact**
2	Minor Threat	**Threaten efficiency or effectiveness**
1	Insignificant Threat	**Can be dealt with**

CHAPTER 6: RETURN ON INVESTMENT (ROI)

Since there is a lot of uncertainty, the assumption of a 30% ROI was placed in order to calculate prices and required sales. This calculation was used as the base for other options with higher and lower budget.

A 30% ROI is deemed reasonable since the SpaceX Falcon 9 has ROI of 27%, however, it is a very specialized and niche market that it is operating in.

CHAPTER 7: COST

Since there is a lot of uncertainty, the assumption of a 30% ROI was placed in order to calculate prices and required sales. This calculation was used as the base for other options with higher and lower budget.

After removing the launch cost of $300 million which is set aside for the Falcon Heavy launches to get the craft into space; approximately half of the remaining $1.2 billion budget will be spent on labour and half on non-labour (materials, test equipment). This $600 million dollars allocated to labour will be split into 4 phases, phase A through D.

Phase A will be spent developing the concept with minimal materials purchased and around 10% of the budgeted $600 million will be spent in this initial phase.

During phase B a prototype will be constructed and the requirements will be created, this phase will be around 25% of the budget.

In phase C an engineering model will be created which includes testing in a vacuum and having a basic working model, this third phase will be the most expensive using 35% of the budget.

In the final phase D – the final phase - the flight unit will be fully constructed and this final phase will use the remaining 30% of the budget. Following this there is more work to be done on operations (Phase E) which will probably need around 20 full time employees. The cost of these employees will be considered before the allocation of funds to the initial 4 phases since this final stage is imperative to the mission but also the least expensive.

The $600 million dollars allocated to non-material will be quite front heavy in terms of the price load. Every piece of equipment and hardware sent into space must first be tested to ensure it is space worthy, which is a highly expensive process but only must be done once per item. This means that the initial phases of the project's material testing will be disproportionately higher than the rest of material acquisition and construction creating a larger than expected price for the initial creation of this craft, however any additional models created or future variants would cheaper to produce since the cost heavy process of testing would already be completed. This makes the costing of this project make appealing to organizations or companies that may wish to have additional similar projects and missions after the Bennu mining mission to prove the viability and gain capital, since future craft would be cheaper to manufacture.

Cost Assumptions

This project understands that there are more complex and in depth methods of analysis and budget planning, but due to the nature of this research project where the engineering team is designing the craft in tandem with the budget and business plan being created it made it impossible to do, especially with the limited time and resources available to the group. There are many large assumptions being made with regards to budgeting and the spread of financial resources. These include that salaries and available staff remain similar to current levels and a competent management team is in place that sticks to the allotted budget. However, it is a very viable system that is being proposed and would work well as a framework to build such a project out of.

CHAPTER 8: FUNDING & CAPITAL

A public-private partnership was considered for this assessment:

Public-Private Partnership		
Benefits	**Downsides**	**Upsides**
Government legal support	Conflict of interest	Public justification and approval
Flexibility over time and budget	Bureaucracy	Large quantities of capital
International expansion possibility	Political interference	Stable results
Large pool of investors		Discoveries and sectors overlaps

The target total of funds to be raised through investment is $1.5 billion. This does not all need to be acquired from the get go and can instead be in two bursts, one round of investment from the government to create a working model and test mission, then the next round from private investors to allow for the actual completion of the mission.

In order to maximize the benefits, ideally the government would invest around 50% of the total capital for the initial development and test mission/prototype. The government could be persuaded to fund this test mission with the promise of helping to create a new industry within Canada; while providing the mission with the funds needed to prove its viability. By having the government fund this initial mission it would cover the main costs of testing, designing, and manufacturing a test craft which not only decreases the investment needed from the private sector, but also makes it a less risky decision. Additionally, if Canada were to be funding this project it is likely that policies beneficial to space mining and sales of products mined in space will be passed in government. This too will reduce risk for private investors as well as create a more welcoming market for competitors, however the benefits far outweigh the costs. A major assumption being made that the government can be convinced to fund a project like this, however there are many different angles available to lobby the government from the little to no environmental impact to the incredible revenues and capital that it would generate for Canada through this industry.

The remaining 50% of investment will come from private sector, which will be far easier after a successful test mission. The test mission can be kept to around 50% of the cost by performing it in atmosphere, just to prove it is possible and that the technology is functional. By having a successful mission it will greatly reduce the risk level of this project opening up the potential breadth of investors to those who are more risk averse. An additionally factor that can decrease risk is if the government also passes beneficial policies for this project and industry, further increasing chances of gaining investment. Given that the space industry is rapidly growing and full of potential for profit, it is expected that there will be no shortage of potential investors to pitch this project to and acquire funding. The major assumptions being made here are both that the government

does provide funding for the initial test and also that investors are found to cover the remaining portion of the budget.

The planned timeline of these two rounds of investment allows for the government to no longer be involved during the gathering and sale of the final product. This eliminates any red tape and additional costs such as taxes from being placed on the sale of fuel and allows for private investors to feel more comfortable that there will be no interference in the company from the government.

With this combination of private and public funding the project will have the benefits of both forms of investment while negating most downsides. Additionally, decreasing public sector's influence & investment after the initial test mission allows for a complete transition to private investment and a purely profit oriented mission in a very lucrative industry.

CHAPTER 9: FUNDING & CAPITAL

Sales Location

The location chosen to place the orbital gas station is in a High Earth Orbit/CIS-Lunar orbit. The method of transfer of fuel will be basically a gas station in space. Craft will dock with the station and refuel using the appropriate apparatus that is available. There will be many variations of apparatus initially and as a more universal design for refueling is adopted the station will be changed accordingly. The closeness to Earth will allow for near instant communication with the station for both ground control and the ground teams of client vessels. It will also allow for constant visual access, ease of access for repairs, maintenance, and retrofitting, as well as convenience for customers due to its close location.

Benefits

A benefit of selling in a High Earth Orbit(HEO)/Cis-lunar orbit is that it allows for the refueling of ships immediately after they exit orbit, as well as those returning to a HEO but not intending on entering atmosphere. This allows for potentially twice the number of initial customers since fuel can be sold to both single use missions as well as return trip missions such as those heading to the Moon or Mars. With the growth in the space industry we expect there to be a proportionate increase in both single use exploratory craft as well as return trips for more permanent missions. By being located in a HEO our gas station will be able to service both of these styles of clients.

A key benefit for a HEO station is the ease of access for repairs and maintenance as well as retrofitting the station with the most up to date refueling apparatus. Since there is no single universal refueling system and instead it is more akin to electric cars today where

every company has their own slight variation, by having our station near to Earth it allows for updating and changing the fueling system to keep in line with the current and most popular styles.

CHAPTER 10: METHOD OF SALES

Contracts

The primary method of sale will be through large contracts and recurring contracts, such as those for resupply missions or large one way trips. A clear potential client for both of these styles of missions is NASA with their planned creation of a moon base as well as a potential future Mars base. These contracts will provide a steady and consistent revenue stream while allowing for the remainder of the fuel to be sold to smaller, single-use missions such as exploratory craft heading far into the solar system. Other large potential clients that are currently in existence are military organizations such as the United States Space Force. There is also the assumption in place that there will be future space- based corporations and organizations that will be in need of orbital refueling.

Sale Price

The price of the fuel sold to ships will be determined using both the cost of fuel on Earth and the Delta V – or cost of getting 1kg of fuel from the surface of the Earth to a HEO. Using these two values the price of fuel will be determined with a variable system allowing for the project to maximize profits as well as keep a constant competitive advantage.

The estimated cost of fuel being sold in a HEO using just the delta V would be around $8,000/KG of fuel. This provides a more than enough fuel to pay for launch costs on a Falcon Heavy Rocket as well as fuel to travel to and from Bennu. There will be varying quantities of fuel brought back per trip depending on the orbit of Bennu and storage in the ship, however the lowest quantity of fuel at 13,435KG returned would have a value of around $107.5 million providing a relatively fast payback period. The quantity of water returned varies from the lowest at 13,435KG up to an estimated 50,524KG which is equal to about $404 million during the second and third cycles, showing the great range it supply being delivered.

There are different levels of fuel being returned to the station on each trip because of the distance between Bennu and Earth which is due to Bennu's orbital pattern around Earth.

Benefits

The main benefit of this sales plan other than the incredible profitability is the ability to continuously change the pricing of fuel to maintain a constant competitive advantage with maximum profit per unit of sale. This allows for a near monopoly on all space fuel sales since any potential competition can be priced out of the market easily, and there will be vast quantities of fuel stored in the station after the first mining mission returns.

Additionally, the quantity of fuel that will arrive in each shipment is known from the beginning and sales can be planned out far in advance using this knowledge.

CHAPTER 11: CONCLUSION

After reviewing the situation and creating a business plan, this project seems not only feasible but quite profitable too. By being the first organization in space to operate an operation such as this it provides the company with a foothold in this industry and all the prerequisite technologies to expand to other mining operations for valuable elements such as rare earth metals.

However, during the process of creating this business plan many assumptions were made with regards to the market and pricing as well as government cooperation. If these assumptions hold true then there is good reason to pursue this business idea and any future opportunities that may present themselves using the technology and infrastructure developed during the Khepri project.

APPENDIX: LITERATURE REVIEW

The following articles were considered as part of this project, and provide background information vital to this assessment.

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