Is there a business opportunity for the exploration of resources on celestial bodies?

Master Research Thesis

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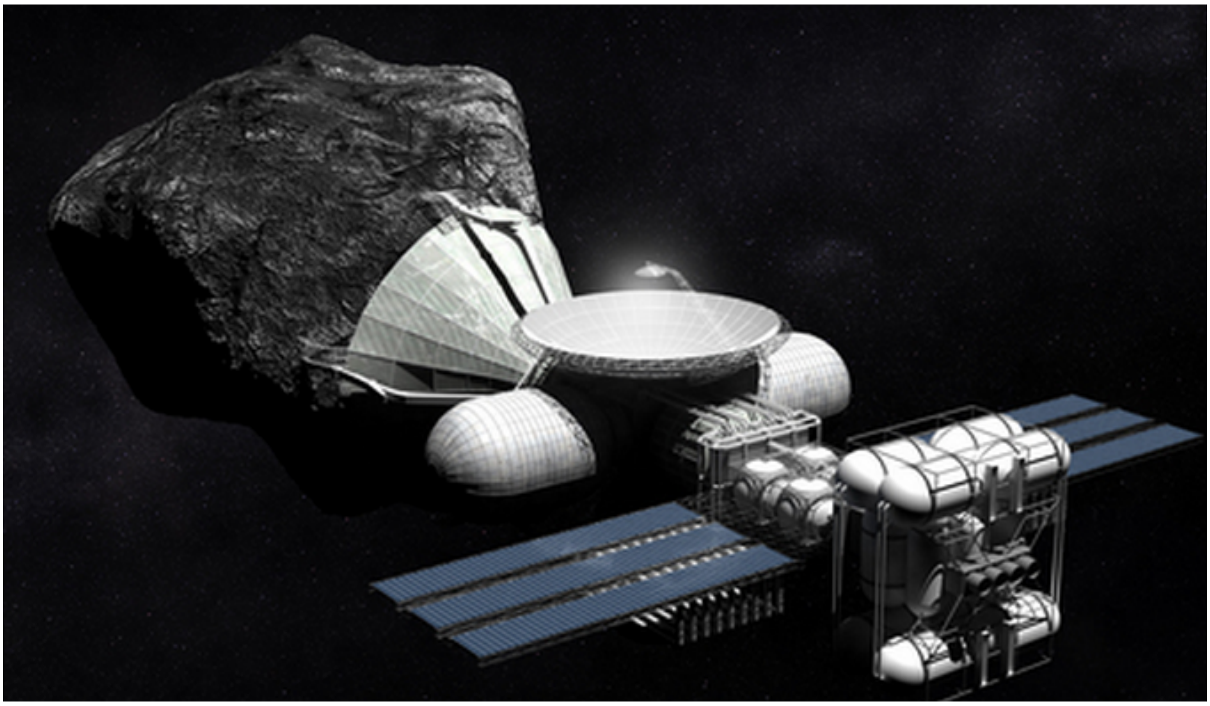

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Summary

This paper will provide an analysis about a new possibility of business: Exploiting ores on celestial bodies. Our essay is considering strategic, financial and supply chain aspects. The study starts with a detailed introduction, introducing the subject and all the elements, which has to be analysed to answer the question of possibility of such mission. Every aspect cannot be studied in our essay, so we carefully choose three of them related of our study fields. The first chapter will provide a strategic overview of the mining industry on Earth and a potential strategy to implement on Space. The second chapter details financial aspects and provides some indicators materialising the project viability. At least, the third chapter deals with Supply Chain management and its future issues. In the conclusion, we will underline the question of Human resource management issues and we will provide our point of view to the question of this potential opportunity of business taking into account the key elements which have been analysed during all the document.

Key words

Ores - Metal - Mineral - Celestial bodies - Asteroids - Mining industry - Exploration - Exploitation - Resources - Net Present Value - Supply Chain - Finance - Strategy

Minerais - Métaux - Minéraux - Corps célestes - Astéroïdes - Industrie minière - Exploration - Exploitation - Ressources - Valeur actuelle nette - Supply Chain - Finance - Stratégie

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1.Introduction

1.1 Why is this subject important?

1.1.1 Overconsumption of natural resources and space alternatives

A data, published by the Global Footprint Network, indicates that on August 2, 2017, humanity had consumed all the natural resources that planet Earth can renew in one year. This figure is an indicator of overconsumption of natural resources. Indeed, our planet has limited stocks and the question of Earth over-exploitation is becoming more and more addressed. Besides the overconsumption of biomass products, one of the main issues is our consumption of non-renewable resources such as minerals, metals or fossil fuels. This increasing consumption of resources is linked to the rapidly growing human population and activities. Some countries are considering alternative consumption models, but the depletion of natural resources is a genuine problem. In order to face this situation, studies have raised the possibility of exploiting celestial bodies in space in order to extract resources from them (Keck Institute for Space Studies, 2012). Can be considered as celestial bodies other planets, natural satellites or near-earth asteroids.

Majority of the studies that have been done today are focusing on near-earth asteroids because there is a higher probability for their exploitation to happen in a near future. Thereby, our paper will focus on the exploitation of those space objects.

1.1.2 Near-earth asteroids: a mine of untapped resources

Asteroids are supposed to be easier to access because of their low gravitational field, thus, this is more direct for spacecrafts to travel back and forth to the celestial bodies. According to the spectral classification of asteroids, they are divided in 3 major types: The C-type (their surface is mainly composed of carbon, rock and they contain water), the S-type (their surface is made of iron, magnesium and little of nickel and platinum group metals) and finally the M-type (that contain pure nickel and iron, and small platinum group deposits). Those minerals and metals are very interesting for the needs of human activities. For example, an asteroid half a kilometre in diameter, highly concentrated in platinum could represent 1,5 times the world-stocks of platinum group metals.

There are two different ways to exploit resources on celestial bodies (these techniques are used on Earth as well): mining and biotechnological process such as bio mining and biogas (microbial based mineral extraction processes). Considering this cutting-edge technology will be operational in the coming years, the exploitation of resources will have two purposes:

- To cover the needs of human bypassing the scarcity of resources on Earth.
- To use the asteroids resources in order to cover the need of spacecrafts and satellites for longer duration or further space mission.

1.2 How would it be possible to exploit celestial bodies?

Two very important questions when addressing this subject are the technological and the legal aspects. In the development of our document, we start from the premise that these questions are settled. We will try to explain in a general way the current situation concerning these two aspects and what are the possibilities. However, we do not master these subjects and therefore we have decided to dwell on the managerial aspects of the exploitation of celestial bodies.

1.2.1 Technological aspects

The technology is not available yet but in development. The searches are led by few companies who believe in this future business opportunity (Deep Space Industries, Planetary Resources, Moon Express...). The last twos are planning exploration missions by 2020. For example, the company Deep Space Industries are organizing their project of asteroid mining in 4 phases: prospecting, harvesting, processing and manufacturing. Those four steps are planned to be accomplished up space thanks to robotic spacecrafts and large structure located near-earth. For now, water and precious metals are the goals of those companies. In addition to the technology it will be important to determine the cadence of the missions: indeed, there are launch windows that need to be respected. This condition could reduce the number of missions has it could not be possible to unload spacecrafts and reload the for immediate relaunch.

1.2.2 Legal aspects

After the technology question is answered, it will be absolutely necessary to implement a legal framework. Indeed, anything companies do up space requires them to be represented by a nation. However, in 1967 several large countries signed a treaty preventing any state from claiming ownership of celestial bodies. Nevertheless, at this time, already two countries have legislated on the commercialization of space: The United States and Luxembourg. Indeed, in 2015, with the Obama Space Act, the United States bypassed this treaty by proclaiming that individuals or entities in the private sector will be able to claim "the resources from celestial bodies" in order to commercialize them. More recently, the first European law concerning the exploitation of space resources was promulgated by Luxembourg. Indeed, this country in which several space companies such as Deep Space Industries and Planetary Resources are set up, aims to become the first European pole for the exploitation and commercialization of space resources. This law, which became effective on August 1, 2017, allows private sector companies established on the territory to extract and bring back to earth the resources of celestial bodies after obtaining approval from the Ministry of the Economy. These two initiatives surely represent the first step towards an international organization on this subject. However, several countries and organizations remain diametrically opposed to these laws for ecological reasons for example (according to them, the possibility of bringing back resources from the space would incite even more the overconsumption of the stocks already present on Earth).

1.3 From a business point of view: what might be possible?

1.3.1 Innovation of context: sending the mining industry to space

Innovation of context is the result of the combination of the society needs ("market pull") with the evolution of technology ("technology push"). It is called "an interactive model of innovation" (Paul Trott, 2012). The idea is born from people that realised the potential opportunity to develop a new business of primary resource who will complement the existing traditional business on Earth, combined with the feasibility of the available technology. Indeed, this innovation is not a new product but a new source of product acquisition. An important question raised is: would that be a creation, a transposition or a combination of industries? The answer depends on the choice of management for this new business opportunity.

At this time, the space mining industry is at the development stage, it means that the firms that are willing to get involved are not operational yet. At this stage, these companies have to combine their creativity with the need of efficiency (Paul Trott, 2012). By creativity, it means that they do not have the pressure of profitability at short term, so they can put all their resources in the development of the project and all the ideas that are related. But once these start-ups will be operational, they will have to manage efficiency day to day and keep going to create new solution in order to improve or correct the ones developed at the first step. What is important to manage in this type of innovation is the uncertainty. Indeed, there are a lot of risks brought by this new context and especially a risk regarding profitability for investors. Moreover, firms have to handle numerous project in the same time and to increase the skill level of each departments, which is a real challenge for those involved in this operation. (Paul Trott, 2012)

1.3.2 Four dimensions to study the feasibility in term of business

As previously stated, the analysis in this document will be based on the managerial aspects of the exploitation of celestial bodies. The question that will be addressed is: "In term of business perspectives, in the coming years if mining exploitation on celestial bodies will occur, what would be the main variables to observe?". To answer this question, it is necessary to study four dimensions: the strategic dimension in order to understand the market and its stakes, the financial dimension in order to define if this project could be viable and the supply chain dimension to identify the actors and their interactions. Finally, we will be able to conclude and give a statement on this subject.

2. Strategic dimension

2.1 Mining industry Market

2.1.1 Overview of the mining industry strategy on Earth

Us analyse will be based on the idea that the primary exploited resources on celestial bodies will be mineral, metal and volatiles because of the high profitability expected. Exploitation of water and gas is mainly for scientific purpose by supplying spacecrafts in order to allow them to visit further destinations (discovery of planetary, knowledge about origin of universe). Metals and minerals can also be used for this purpose, but the main purpose is to bring them back on earth to supply the different industries. In order to understand how the mining industry process can be transposed on asteroid, planet or natural satellite, an overview of the strategy currently applied on earth is necessary.

First of all, it is necessary to define what types of resources can be extracted on our planet. There are three types of resources than are currently exploited by the on-earth mining industry: minerals, metals and volatiles.

- Minerals are substances that occur naturally on planet Earth and are not formed by organic residues. The technique that is used is mining. (Xerfi - 2016)
- Metals are solid mineral elements that are able to conduct heat and electricity. They also have the attribute to be deformed under high heat and pressure. Common metals mined on Earth are: bronze, copper and iron. (Appendix 1).
- Volatiles are substances that evaporate at normal or relatively high temperatures. Water is currently the most problematical resource, it is a major public issue to know how to manage water consumption.

Mining industry has largely evolved in the recent years. It has gone from a very fragmented industry at the beginning of the years 2000 to a more oligopolistic structure. There is indeed high rivalry between those actors. In this industry, the main sources of competitive advantages are the costs. As the offer is sensibly the same for every company, it is important for them to be able to propose lower prices than their competitors. Moreover, recently, the industry has seen the risk of sovereignty increase a lot: governments, particularly in emerging countries are looking to maximize the return from their national resources. In general, declining prices and raising debts have forced a restructuration of this ecosystem. Companies are postponing their new projects and are focusing on brownfield investment. They are reconsidering their strategies in order to strengthen their competitive advantage. New strategies include: supply chain and productivity improvement, partnership with other companies, company modernisation, reduction of greenfield investment, partnership with long term investors, focusing on one or very few range of product and geographic zone. In this industry, China is the biggest actor. It is the first supplier of resources but also the biggest consumer.

As every other industry, the mining industry has a life cycle for its products. The activity in mining industry consists in extracting ores but also in selling products. The first step of the value chain consists in exploring and setting up the sites. Those are tricky parts because of the need to obtain authorizations from local administration that are not always easily gained. Time required for these two steps oscillate between 2 and 15 years. The next step is the extraction of the targeted ore. Then the process ends with the separation of metals and minerals by different types of processes. The final step consists in selling the products. One variable to take into account is the duration of one site that varies between 2 and 100 years, depending on the type of resource.

Regarding factor of production, massive long-term investments is needed, particularly in the exploration and mine set-up stages. Indeed, the mining industry is one of the most capital-intensive businesses, comparable to other industries such as oil and gas or nuclear power.

2.1.2 Overview of the mining industry strategy on Space

There are two objectives for the companies who want mining on Space. At first for commercial purpose by covering the future needs on Earth of human and secondly to cover the need of energy for long duration mission on Space. Currently the distance of travel is limited by the quantity of fuel that is possible to carry in a spacecraft. By opening energy station on the Moon for example, it will be possible to pursue missions in unexplored Space environment. The gravity on the Moon is six time lowest than on Earth, the consumption of fuel for a spacecraft taking off from the Moon is importantly reduced than from Earth. The famous entity NASA is developing robotic prospecting and mining capabilities necessary for space exploration through different programs: For example, the Regolith Advanced Surface Systems Operations Robot (RASSOR), the Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE), and the Moon Mars Analog Mission Activities (MMAMA). That shows this project is considered very seriously, this is not only an idea from few start-ups whom expectations of financial returns will be never reached and moreover, with a high probability of failure. The use of robotic or semi-autonomous mining equipment are the key to achieve the goal of this mission. Developments are already testing on Earth with big players through the mining industry.

2.2 Mining industry and Space mining industry relation

2.2.1 Strategic groups of Mining Industry on Earth

In order to understand the structure and the position of leading companies, we created a map of strategic groups. The table of strategic groups is presented in the Annex part (Appendix 3). It was created with data provided by the Global Mining Industry, Xerfi, 2016.

This table was drafted, taking into consideration three variables:

- ➢ CAGR (Compound Annual Growth Rate): The compound annual growth rate is the annual growth rate of an investment over a specified period of time longer than one year. Here this is for the 2010 - 2015 period. This indicator is in percentage.
- ➢ Diversification: This means the variety of product the company is exploiting. The scale is between 1 and 12 ores exploitation.
- ➢ 2015 Revenue are only Mining related revenues, expressed in Euros.

Four groups were identified in this strategic groups map: The group 1 represents only one company. This group represents the leader of the market characterised by a very high turnover (153,65 billion euros in 2015), high diversification (between 8 and 10 range of product exploited) and with current profitable investments (+ 6% CAGR).
The group 2 represents the following leader on the market. They are characterised by a high revenue and a high diversification. However, their investments are losing value and are not profitable.
The group 3 represents companies which are not diversified (between 1 and 4 range of product), with a medium/high turnover and a positive CAGR which means the company chosen profitable investments.
The group 4 represents those which are not diversified, with a medium/high turnover as well. There CAGR is negative which means the company did not make profitable investments.
This analysis shows that companies are highly diversified or highly concentrated.
Very few actors are sharing a high percentage of the total market revenue, the rest is for smaller companies, hence the characterisation of Oligopolistic industry.
The rate of CAGR is a characteristic of the current economic difficulties that have to face mining companies. Indeed, profitable investments are more complex to find. There are very few companies having a positive rate of CAGR.

2.2.2 Near Earth Asteroids extraction: Pioneer companies

Today five companies have created their Business Model towards exploitation of resources on Asteroids or satellite:
Planetary resources are an American company based on Luxembourg. This company expects to mine Asteroids in order to get at first water and use it as propellant for spacecrafts and satellites on activities and secondly to mine ores to bring the natural resources from space within humanity's economic sphere. Currently, their advancement remains at the stage of exploration. The company raised 50 million $ of funds, Google is one of investors.
The second is Deep space industries, an American company based on Luxembourg. This company has the same purpose than the previous one: to exploit water and minerals on Asteroids. The goal is to provide technical resources, capabilities, and system integration required to discover, harvest, process, and market in-space

resources (for Satellite refuelling or for Earth consumption). Their first exploration mission is planned in the coming years. They set up a partnership with Luxembourg government and universities.
Three other companies are expecting to exploit the Moon, all of them are American companies based in USA. Moon Express is developing a robotic spacecraft for low cost missions to the Moon, asteroids, and Mars. The company is still developing several robotic spacecrafts for future missions of exploration to the moon. They plan to harvest a sample back on Earth in 2020. They have a partnership with NASA. The company raised 53 million $ investment funds. They are among the five finalists competing for the Google lunar Xprize, which the aim is to send a robot on the Moon. Shackleton Energy wants to exploit water on the Moon and to create fuel stations in Earth's orbit. Lastly, Astrobotic develops robotic and expect to deliver payloads to the lunar surface, and prospect for resources using rovers and landers.

2.2.3 What will be the future of mining industry?

Mining industry will face many challenges in the coming years. First, by implementing strategies to remain profitable in this economic turmoil. And secondly, take into account that plenty of resources will be no longer available on Earth in the coming decades and investing into new explorations.
The future of mining industry is partially related to the future of Space Industry. Space industry has experienced a huge increase of investment: 13,5 billion of dollars in space start-ups since 2000. Opportunity of return reaches 10 to 100-time return. Most of investments concerning small satellites technology development. But a large amount of investments concerns the development of travel cutting edge technologies. Moreover, many private actors became very big players such as SpaceX and Blue Origin. Cost reduction is the main reason of growth. It is also easier to enter in the market since national players had reduced their budget (NASA, ESA) and their oligopoly situation. Companies are considering how space can be appealing and realise the multiple opportunities of business. The mining industry will have to reshape its oldest configuration to prevent the future scarcity of ores and probably be associated with space actors and governmental Space Agencies.

3. Financial dimension

3.1 What are the financial variables for the exploitation of celestial bodies?

3.1.1 What is the economic scheme of mining industry?

Every company that gets involved in a project expects a return on their investment. There are different ways to calculate the relevance of their investment. As said before, our analysis is based on the comparison between on-earth mining industry and what space mining could offer. According to Xerfi study on the mining industry published in 2016, it is known that growth of on-earth mining industry is highly linked to GDP growth. Indeed, in economically growing countries, demand is rising, and population is consuming more and more (Appendix 6). As mining products are first step of the supply chain for a lot of industries, the mining industry has strategic position. It is forecasted that the world population will grow until 9 billion of inhabitants to 2050 and the urbanisation rate will be about 65%. Moreover, it is noticeable that in 2030 Asia should represent 60% of the world's population. This information combined with the stable growth of 3,7% per year for the GDP until at least 2020 is a good indicator. It means that the rising demand for "developed countries" products, such as new technology, is inevitably accompanied by a rise in the demand of mining products (minerals, metals and water).

Nevertheless, despite the fact that the mining industry experiences a 350% growth of its exportations between 2004 and 2014, the production is on the downward slope. For example, the growth of iron's production (that is the first exported ore) is slowing down since 2014 (from 8,5% to 3,5%) and it should continue. Moreover, the profitability did not reach a good level, reaching record lows in 2015: decreasing by 93,1% between 2011 and 2015. Today, with the ongoing slowdown in the Chinese economy, coupled with the weakening economic context in other developing countries, including Brazil and Russia; demand for metals and minerals is decreasing and prices are downfalling. In the near-term future, the mining industry does not seem flourishing, but the long-term forecast remains positive considering the continuing growth of the population and the intensive urbanisation which occurs in developing economies.

The mining industry is characterized by highly volatile prices. Reasons are various: It is explained by the emerging market growth which increased the price and, in another hand, the financial crisis in 2008 plummeted the price. After a brief recovery, slowing emerging markets, stagnant mature economies and high supply pushes prices down. While mining groups have control over production levels to influence prices, two other components: demand and speculation, are in the hands of client industries and the global market. A last element to take into account is random events (political or environmental) which influence prices. In annex 2 there is a table of prices evolution from 1980 to 2015. Today the trend remains the same than 2015, the price continues to decline. (Appendix 2)

3.1.2 How to analyse profitability for this project?

For this type of project, the Net Present Value is a quality tool. It is used to assess financial feasibility. The principle is to calculate the present value of the future revenues of a project.

In the document "The technical and economic feasibility of mining the near-earth asteroids" by MJ Sonter (1998) it is discussed that the formula of Net Present Value (NPV) should be adapted to the aerospace industry and aerodynamics to be efficient. Before calculating the NPV of a space mining project it is necessary to define a project that is “realistic”: for example, what celestial bodies need to be targeted, what type of propellant will be used, what materials will be used etc… Indeed, it is really necessary that all the variables took into account for the calculation will be achievable. In the calculation it is also important to take in account the sensitivity of the market. For example, what if the price of the resource brought back to earth drops because the high rise in the offer. This needs to be included because it could totally change the outcome of the project. Concerning the formula, “the present value of a receipt R obtained in year n is: PV = R x (Y +y) ^n (Sonter, 1998). In the case of asteroid mining, the NPV depends on three important criteria: the cost of the launch of the spacecraft and the return on earth, the time needed to succeed and finally the total mass of resources that can be brought back on earth and the price it can be sold. Currently, as no company involved in space mining has published results or financial forecasts it is complicated to calculate Net Present Value. Indeed, it is necessary to know what revenues are expected each year after the beginning of the project. In 2015, the average profitability ratio for the mining industry was about 10% and the one of space industry was about 21%.

The Appendix 6 will be used to illustrate the Net Present Value calculation with an example. This project is estimated at 145 million of dollars. If we take the average rate of return by for example, Appendix 5 shows how costs are split for a space mining project of 145 million of dollars. In the mining industry it is consistent to use a project duration of 10 years. The discount rate used is 1,40% (31st January 2017) With an annual profitability of 10% it means that every year the company should expect 14,5 million of revenues. Using the NPV calculation we obtain a result of: -10 567 131,06 €. It means that, with this profitability level the project is not interesting. In the other hand, if we use a profitability rate of 21%, as in the space industry, the present value of the project is 137 309 024,77 €. To conclude, the companies in this new industry must realise high returns in order to be profitable.

3.1.2 Create partnerships to finance celestial bodies exploitation

One type of partnership that can be chosen is the public-private partnership. They are contracts between an agency of the government and a private company. It is generally used to finance projects that have a public utility. For example, public transportation or space exploration. Financing a project with this type of partnership is interesting for the private company because it is an important source of income. But it is also very interesting for the public agency because it is the opportunity to improve their services or projects (such as space exploration) without the need to organize operations. In an article published by Space Policy, Carlos M. Entrena Utrilla suggested that the example of COTS (Commercial Orbital Transportation Services) should be applied to Asteroid mining. As stated in this document, this project as shown the efficiency of public-private partnerships in the space industry. The Commercial Crew Program (a NASA’s program to train astronauts) got involved in this project with the ambition to provide humans a more affordable access to space by creating jointly with private companies the first commercial crew capsule. NASA’s as created the

LCOST (Lunar Commercial Orbital Transfer Services) program, therefore it is coherent to think that this agency could be really interested in financing asteroid mining. It could be really interesting for the new companies getting involved in this new industry to find a partnership with a national or international space agency.

Another type of partnership is cooperation between companies. This idea would occur when the start-ups will set at the harvest period development, meaning when all the explorations and tests will be over. It is interesting for space industry to use the technological knowledge from mining companies on Earth. Even if the environment is different, extraction requires a very specific know-how. And this know-how will help the future conception of robotic structure and for sites establishment, located on Asteroids. For the mining companies, this opportunity can be considered as new growth driver. Indeed, the last years medium performance weakening the traditional business investment sources. Big player will probably see this future investment to be a good opportunity to increase their profitability and will try to get future market share in this new business. The time is too soon for mining companies to express their wish to be part of this business, currently it is more interesting to monitor the technological progress of space industries and adjust their strategy the proper time.

3.2 The example of Platinum Group Metals

To illustrate the revenues that can be expected from asteroid mining, the example of platinum group metals in very interesting. This group of metals include all those six metallic elements: platinum, iridium, palladium, ruthenium rhodium and osmium. This group of metals is very rare on planet earth. However, this is one of the most expensive metal on our planet.

For this reason, platinum group metals are one of the most interesting ore when talking about mining asteroids. The price is high enough to imagine investing it its exploitation and bringing it back to Earth. (Entrena, 2017).

What makes platinum group metals valuable is their scarcity: the demand is growing years after years, but the offer is declining. Bringing back a very rare resource on earth quite easily could create a concern about a new financial bubble. But studies say that there is no risk of overloading the market with this type of ore. The example taken is the following: if it is considered that the asteroid Jollie contains 250 000 oz. of PGM (and other metals derived of platinum) and it is assumed that all this resource are sold at today’s market price the total value on the market can attain 730 million of dollars. (Entrena, 2017)

4. Supply chain Management

4.1 Design of the Supply Chain

The definition of the Supply Chain explained by Quinn in 1997 is: "All of those activities associated with moving goods from the raw-materials stage through to the end user. This includes sourcing and procurement, production scheduling, order processing, inventory management, transportation, warehousing, and customer service. Importantly, it also embodies the information systems so necessary to monitor all of those activities" (Quinn, 1997)

4.1.1 Structure of the Supply Chain

Supply Chain of mining operation on Space will rely on both category of actors: those who will ensure the transportation of product in Space and those who will transport products to the final customer. The network of companies involved is high and require a high level of quality management in order to reduce costs, to respect commitments, to avoid penalties and finally to satisfy final customers. Before to start the mission, the company leading the exploration will have to select a Launcher in order to propel their spacecraft into the space. This is a very critical phase because the complete success of the mission will rely on the launcher performance. If the launch is not achieved properly, the entire mission fails. Once the spacecraft is on the right position in the space to travel until its targeting destination, the management and calculation of direction become the next step. It can be achieved by the company leading the mission on Earth ground station in association with the flight crew in the vessel. Maybe this part of the mission will require an association with national agencies such as Nasa or ESA which experienced the management on ground of space probe (ex: Rosetta). When the spacecraft will reach the destination, the pre-defined site by the operating company, will have to be set up. These abilities will be owned by the company who design the mission and we can also imagine a partnership with actors from the current mining industry on Earth, who's the aim would be to share knowledge about extraction process. When time of exploitation comes, according to the resources available on the targeting Asteroid, a long or short cycle of production will occur. If it is long, several travels from Earth to the Asteroid will be necessary. If it is short, we can imagine that the mission will end with only one travel. In both case the spacecraft will have to travel back to earth. This part of the mission will be very difficult to achieve even if the technology associated would be performant. Indeed, the risks are high because the manoeuvre must be very accurate to avoid atmosphere consummation or to be lost in space. Finally, products will have to be transported to one or several destinations for additional processing before being delivered to final customer.

Customers of mining industry are various and are part of multiple sector: Construction, Automotive, electrical, transportation, Jewellery, Aerospace, and others. Because of the numerous of application, the market is global, meaning the potential clients are located all around the world. Indeed, the mining industry supply raw material almost all manufactured industries.

The model of distribution advised for the mining industry, is the manufacturing storage with direct shipping distribution network or the manufacturing storage with direct shipping and in-transit merge. These models reduce the number of

intermediaries and reduce the time to market. The first model proposes to deliver products directly to the customer, but this model does not suit with high demand, it can be used for ores with very high value such as diamonds. The second model coincide with a higher demand of supply. This model with transit merge allows to regroup ores from different mines (which belongs to the same owner or not) and to make them transit in the same warehouse(s) for one order. For both model's information flow is made from the customer to the retailer to the manufacturer. The model of distribution on Earth is relatively similar to the one we can expect from Space. Indeed, once the supply will land on Earth the problematic of transportation to final customer will be the same than ores just extracted from mines. The difference will be on the method of transportation used and the time needed for each delivery.
(Sunil Chopra, Peter meindl - 2016)

4.1.2 Process view of the Supply Chain

Supply chain is driven by two processes: The pull process and the push process. The pull process is characterised by a response to a customer order, meaning the demand is accurately known. On the contrary, the push process is characterised by an anticipation of the demand based on forecast. The demand is uncertain at the production stage. Currently the mining industry is using the push strategy. Indeed, there is no programming of demand according to customer orders. The mining industry is following global forecast. It can be explained by the long time needed to produce large amount of ores, especially if we consider the time needed for exploration and site installation. In the 21st century economic situation, the production will be sell anyway, because there is demands and needs. An overproduction will affect directly the price of the product on the international market. This bad effect does not prevent to sell production but to sell it at a lower price. Push strategy implies to make economy of scale and to have a high level of safety stock. If the same push strategy is implemented to space mining industry, the forecast will need to be very accurate in order to avoid financial risks by decreasing the market price because of abundance of supply (especially at the beginning when the level of investments is high). But there are some events which cannot be predictable (environmental disasters, wars…) whose direct effects will be a reduction of the consumption. In order to prevent these risks, operating companies in Space can shape their mission according to the direct demand formulated by customers. Meaning turning the traditional push strategy of mining industries into a pull strategy.

The assessment of supply chain performance will be done through key drivers and especially the "Time to market". Indeed, in order to be profitable, the space industry will have to operate in a predefined time which is sensitively similar to operations on Earth. It is important to remember that prices will be indexed on those applied from the existing industry on Earth. If operations are too long and operating cost higher than expected, the company will have to increase the price of the product, making products less competitive and jeopardising sales. In the annex part, the appendix 4 details the cycle of development of the mission)

(Sunil Chopra, Peter meindl - 2016)

4.2 Strategic management of the Supply Chain

4.2.1 Multiple dimensions to manage

Supply Chain management requires to monitor certain number of dimensions. Uncertainty regarding demand is very difficult to manage, especially if the product is harvesting from Space. Indeed, the quantity should be as similar than the needs required on Earth. It is very important for such long mission to forecast accurately the future demand. Companies exploring on Asteroids have to extract ores at a level which maintain price at a certain rate. Meaning the production should not be too abundant but should maintain the scarcity of metal or mineral. For example, a massive extraction of diamonds will plummet the price currently applying on Earth, threatening the profitability on sales of the company and competitors. Moreover, the time planned for a mission must be respected. It is important to analyse repercussions on profitability if the mission takes more time or less time than planned in order to decide if it is reasonable or not to launch the mission. The ores which will be harvesting have to be defined and if for a reason or another, it is not possible to extract them, other possibilities of harvest have to be considered. There is a variety of products available on Space and limiting the mission to one of them is risky because if there are technological failures during the extraction or a bad evaluation of the environmental conditions on the targeted Asteroid, the entire mission could be a disaster. Indeed, the mining industry contains multiple products, and for such long and costly missions it is important to manage the demand from Earth and to consider every possibility of business and to choose the most reliable one. There is another consideration to take into account, the mission on Space will be long and during this time, prices on Earth can evolve positively or negatively. This uncertainty is difficult to predict, political and environmental context are key element on price evaluation. A change is practically impossible to predict. The economic situation evolution is easier to forecast and must be seriously analysed before any missions. At least, any changes on innovation who can have a potential impact on needs or on price have to be considered. For example, the discovery of a new technique of building or a new combination of ores which will change our habits to consume can have significant repercussions.

Risk have to be identified and evaluated in order to define solutions who’s the aim is to eliminate or limit effects and putting them into practice. It is important to share the risk with partners (if the company set up partnerships). Some example of risk directly connected with Supply Chain are: disruptions, delays, systems breakdown, approximate forecast, inventory mismanagement and lack of capacity.

For such critical mission, the supply chain must be very effective smart and innovative in order to understand and to be able to manage the time needed for such actions, the technology associated with needs, volumes and to find a balance between cost and responsiveness.

Partners integrating operations have to be chosen very carefully. Indeed, if the company decide to outsource some activities such as transportation on Earth, stock management… The company have to be sure of their abilities to accomplish their mission in order to not postpone or block Supply Chain activities.
(Sunil Chopra, Peter meindl - 2016)

4.2.2 Optimisation

The optimisation of the Supply chain is achieved by using tools created with mathematical modelling. These linear programming or graphs are parts of operations research (OR). The use of these models in Supply Chain Management has become significant. Companies have noticed financial benefices return by putting into practice operations research solutions. Space mining industries will have to find solutions to manage the complexity of the future Supply Chain. They will have to implement such tools in order to maximise responsiveness and efficiency.

The performance on supply chain in term of responsiveness and efficiency is based on the interaction between the following logistical and cross-functional drivers: Facilities, Inventory, Transportation, Information, sourcing and pricing. The structure of these drivers also affects the financial measure discussed in Chapter two. Optimisation of the Supply Chain's goal is to structure these drivers in order to achieve the expected level of responsiveness at a lowest cost. Moreover, the Supply Chain must be visible and effective. It important for companies to implement a high quality of ERP (Enterprise Resource Planning) which will help planification, analysis …

All steps in the SC process required very high technological tools. The different steps of mining industry are following: Firstly, prospecting: using tiny scouts to locate and evaluate space resources. Secondly, harvesting: using robotic spacecraft in order to extract and transport resources. Following, processing: Separating resources into usable materials. Then, manufacturing: Additive manufacturing in microgravity or transporting back on earth. Finally, transporting the ores to final customers.

It is obvious than new technologies will have a crucial and first role in the mission. It will ease the Supply Chain management by reducing risks regarding human uncertainty issues.

6. Conclusion

The project of mining Asteroids is very likely in the coming years. And it seems that no man will be sent on Space for such mission. At least not at the beginning. Indeed, regarding health issues, recruitment, training and labour cost, it seems very difficult to face all these concerns. For long Mission, zero gravity effects on human body and health issues are unknown. The past missions in Space were not exceeding 12 months. If effects have been identified and analysed, what about 3 years in Space effects? Mission could be very long depending the targeted Asteroid and if the mission is based on human abilities, the risk of failure can be perceived by being too high to launch the mission. Moreover, the recruitment of people over graduated is complicated. These persons should have abilities to pilot a vessel and to land on ground but also to set up a site and mine the ground. These people will have to be trained for many years such as astronaut and cosmonaut with the difference that the training is for commercial purposes, not research. Time in business is value and this perspective of long training can be an obstacle regarding costs. For the current mining industry on earth, in recent years, the industry has been faced rising labour costs coupled with a tight labour market. The solution will be to adopt robotics in order to replace the human action on Space. This automation is slowly adopted in terrestrial mining companies. Several large mining companies are already using autonomous or semi-autonomous equipment and remote virtual control room technologies that allow miners to operate equipment from thousands of miles away. Companies who want start Space mining exploitation will have to develop many tools who will replace human action and launch the mission without human on board. Once the technology needed is developed, it will ease the Human resource management.

In the future, mining industry companies will need to find other opportunities of business due to forecast of scarcity for some ores. Space exploration is one of the diversification possibility. This diversification can be driven with partners such as start-ups working on this topic. Very big actors, leading the market are the most likely to set up partnership for exploration outer Space, even if currently, investments into new projects are not the priority because of profitability reduction. Moreover, although the demand is slightly decreasing during last years, the demand will never be reduced too much because of continuing industrialisation and urbanisation of countries and the rise of population. The risk regarding sales decline is very low.

But in term of financial strategy it is very important to assess the net present value of every projects. Indeed, as this industry is an innovation, there is no real comparison to make the forecasts and the length of every mining project creates a risk for the profitability. Nevertheless, the high value of scarce resources that can be found on asteroids makes space mining very interesting and even necessary to reflate on-earth mining industry. Platinum-group metals are the ore that new companies in this industry should focus on because this is the most beneficial (in the case of bringing back the resources on our planet).

The Supply Chain will be very complex to manage. This complexity of management is due to multiple steps required for the mission. The preparation of the mission will have to be very accurate, the current model of production based on forecast will maybe have to be adapted to the financial risks and turn it into real demand. There is a necessity to maintain prices on Earth in order to remain profitable and for this purpose, the management of production is a key driver. Moreover, the management of uncertainty is essential to limit identified risks. The utilisation of very developed and innovated cutting edge technologies will increase the chance of mission success.

Our readings on the topic give us several points of view regarding the feasibility of the project. Future research and development on the topic will definitely give more precision about technological capacities and financial needs and expectations. Our answer to the problematic is positive: Yes, there is business perspective regarding mining exploration. The question of “when it will occur” is difficult to answer, obviously not yet because the technology is not available. But us analyse developed the idea that with a strong strategy definition, an efficient financial and supply chain management, the project is feasible.

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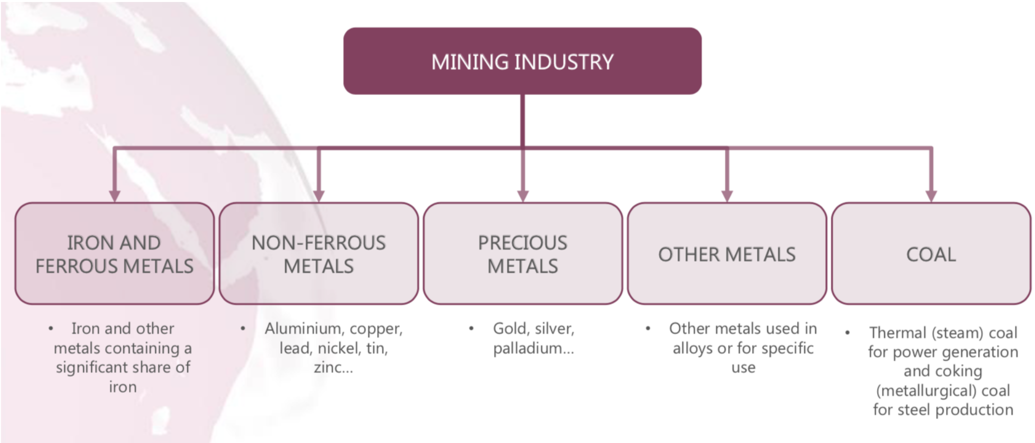
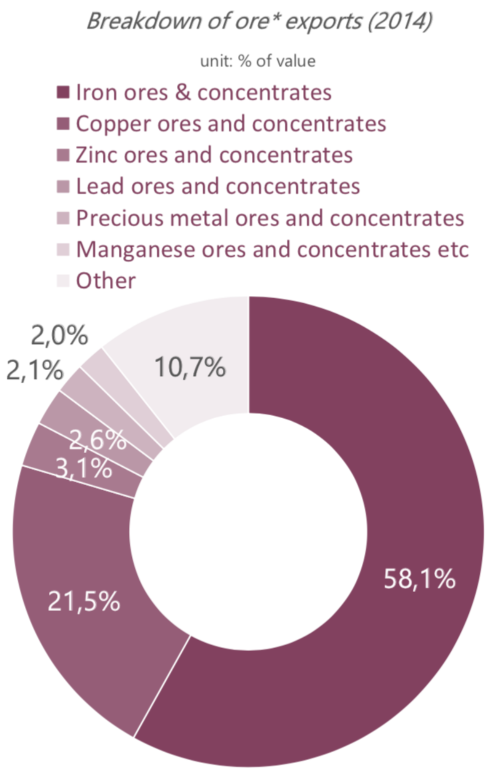
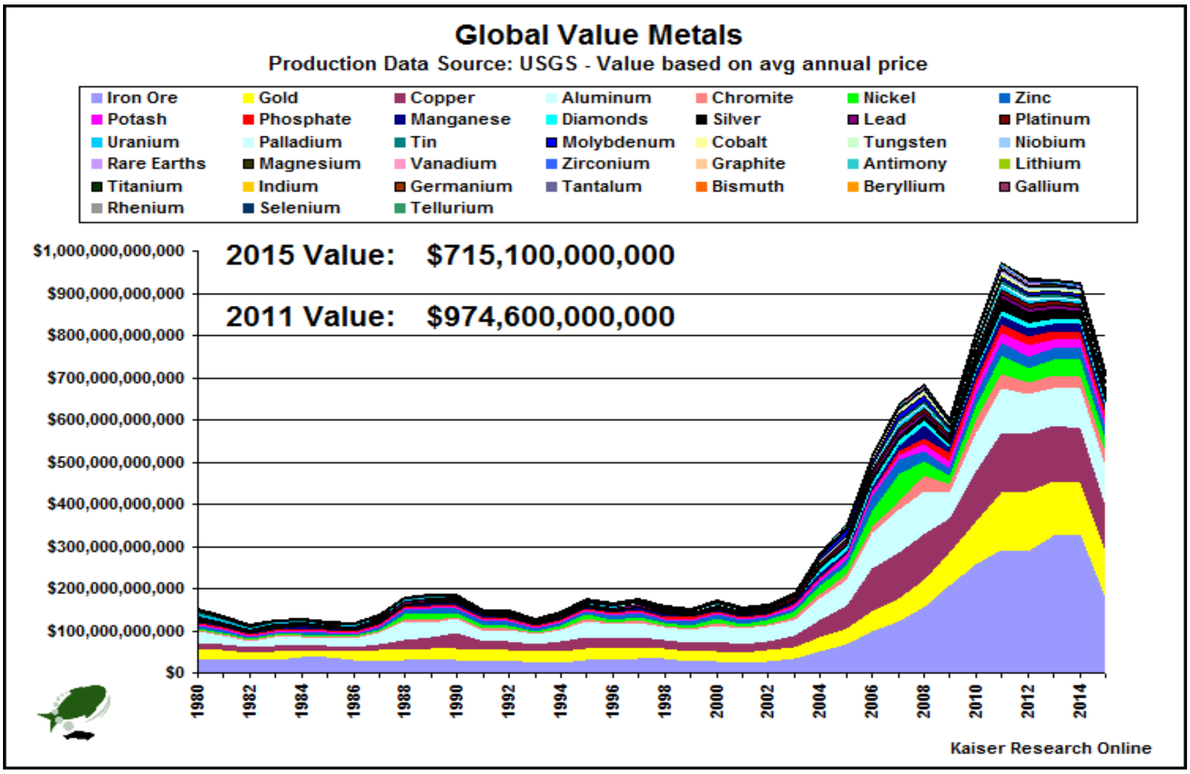
Appendices

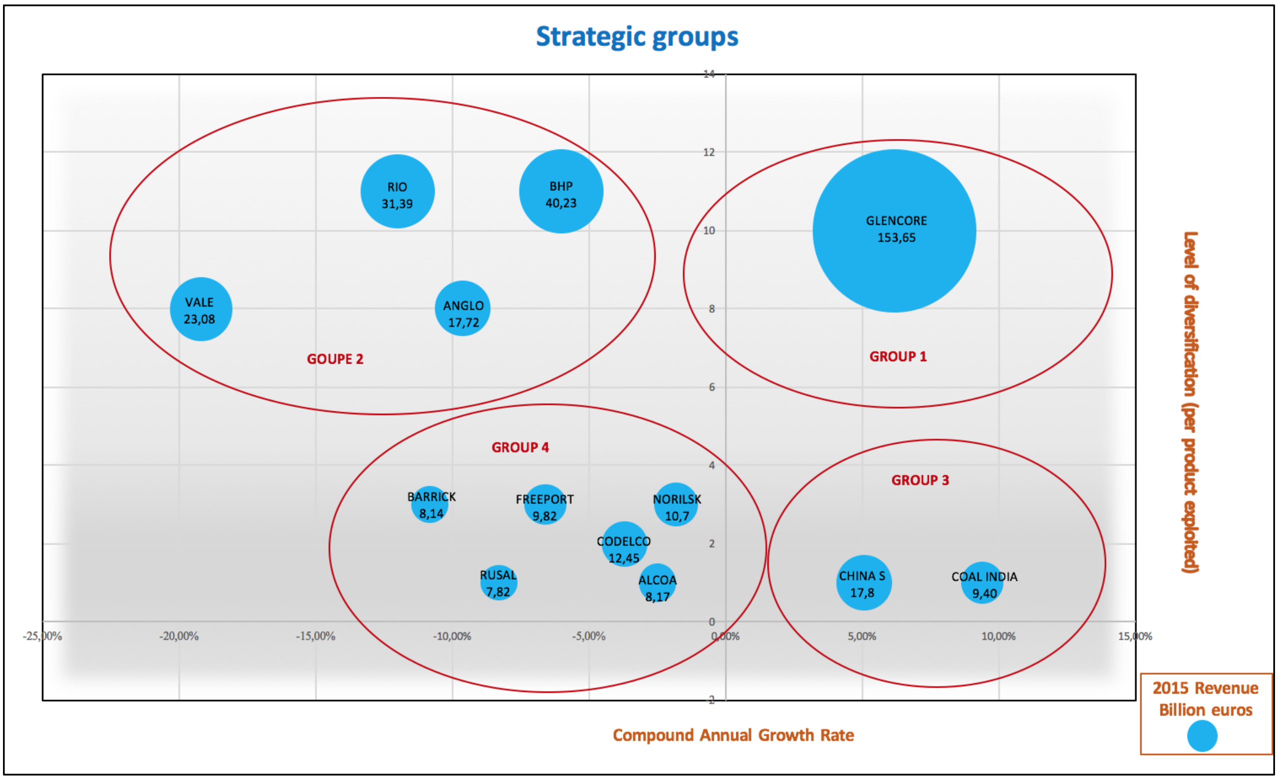




Appendix 1: Category resources from earth. Source: Global Mining Industry, Xerfi, 2016



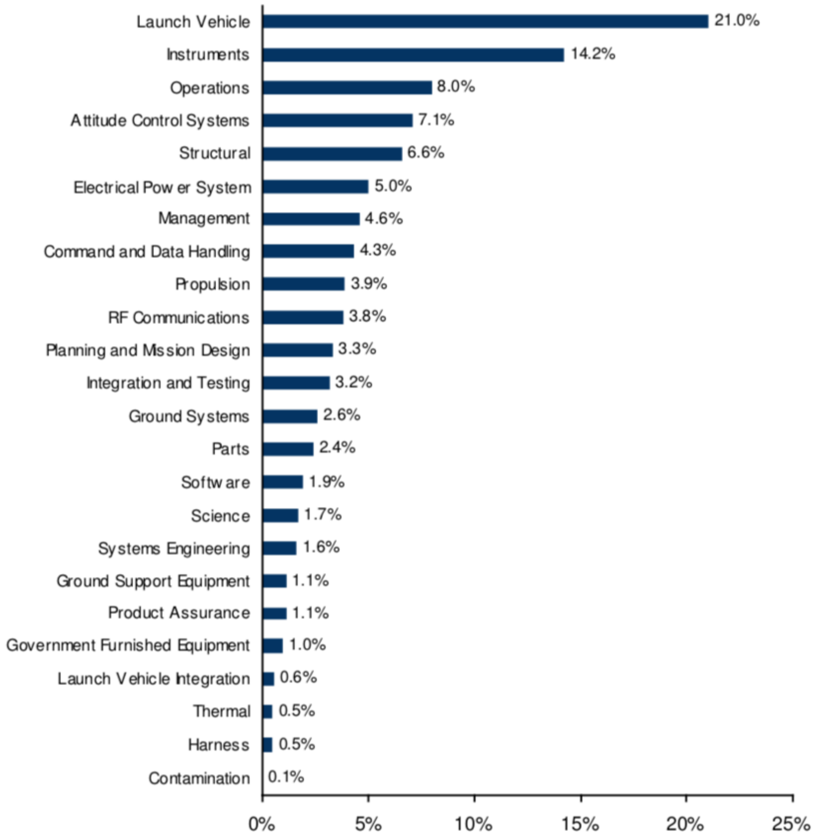
Appendix 2: Global Value Metals - Source: https://secure.kaiserresearch.com



Appendix 3: Strategic groups - on-earth mining industry. Source: Map created with data provided by Global Mining Industry, Xerfi, 2016

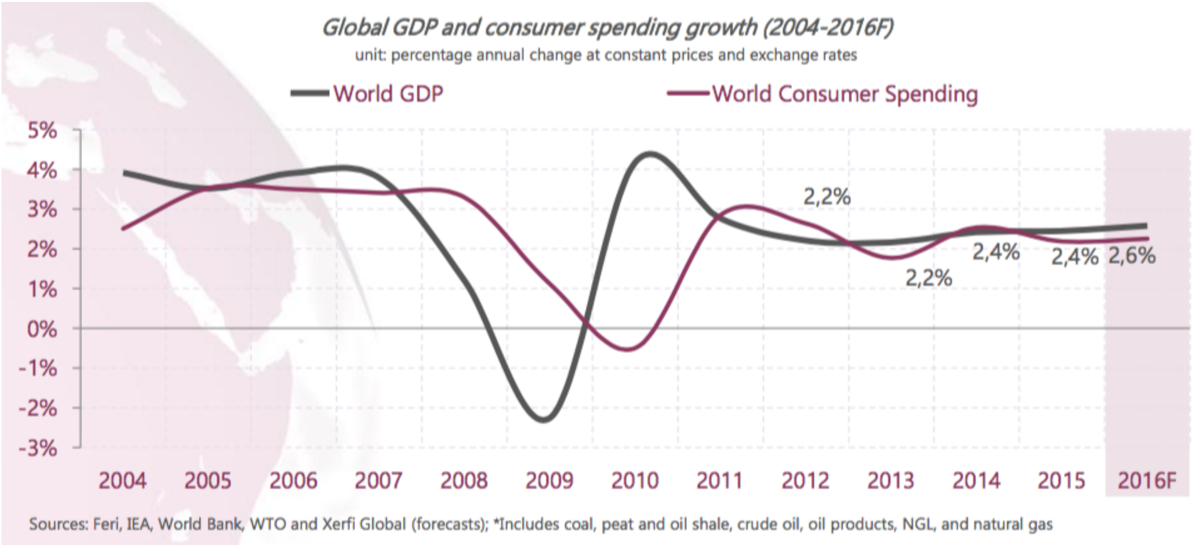
Appendix 4: Development Cycle - Source: Profitably Exploiting Near-Earth Object

Figure 23. Total Mission Cost Breakdown for $145-Million Mission



Resources - 2005

Appendix 5: Cost breakdown for an exploitation mission. Source: Profitably Exploiting Near-Earth Object Resources - Charles L. Gerlach - 2005



Appendix 6: Comparison between global GDP growth and world consumer spending.
Source: Global Mining Industry, Xerfi, 2016