Asteroid Mining: Future of Space Commercialization

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Abstract: **In the future, space commercialization will trigger the quest for space assets. Space investigation will be directed to a shortage of assets as conveying the assets from the earth itself for the advancement of space-based ventures won't be attainable. Receiving the strategy for mining the Near-Earth Asteroids (NEAs) could be a plausible and practical method for conquering this issue and could upset the stockpile of imperative for human civilization. Spectral analysis and ground-based information propose that NEA can contain water, volatiles and some high-esteem materials worth up to billions of dollars. Studies recommend that few new NEAs will be found later on could build the likelihood that asteroidal mining tasks can rely upon low vitality missions. Thinking about the potential applications, Asteroidal mining can be a spine for future space expedition.**

This paper presents a complete survey of assets accessible from NEA, innovative and prudent parts of Asteroid Mining. This literature study can be isolated into four sections: i) Exploration (NEA disclosures and assessed populace) ii) Analysis (topographical portrayal of NEA) iii) Extraction (different strategies to concentrate and procedure the assets) iv) Economical viewpoints (financial investigation and its noteworthiness in upcoming days). We have additionally talked about the attainability to direct a space mission in terms of potential orbits and all other technical difficulties are featured.

Keywords: **Asteroid Mining, Near-Earth Asteroids (NEA), Minerals, Space Commercialization.**

I. INTRODUCTION

Asteroid mining is an idea that includes the extraction of valuable materials from space rocks. Due to their openness, near-Earth asteroids (NEA) are an especially open subset of the asteroids that give conceivably alluring objectives to assets to bolster space industrialization[1].The use of natural assets from asteroids is a thought that is more seasoned than the Space Age. In 1903, Konstantin Tsiolkovsky incorporated the "Exploitation of Asteroids" as one of his fourteen focuses for the conquest of space in "The Exploration of Cosmic Space by Means of Reaction Motors"[2].Numerous materials could be culled out and refined from NEAs which are valuable for impetus, development of life support, farming, metallurgy, semiconductors, and valuable and vital metals. Volatiles, for example, hydrogen and methane could be utilized to create rocket fuel to ship spacecrafts between space habitats, Earth, the Moon, the asteroids, and long way off. Exquisite Earth metals could be utilized to synthesize structural materials just as solar photovoltaic arrays which could be utilized to energized space or on the other hand lunar habitats. These solar cells could likewise be utilized in a system of solar power satellites in circle around the Earth so as to give electrical power to its occupants. Valuable metals, for example, platinum, platinum-group metals (PGMs), and gold are likewise accessible[1].

A) Asteroid Mining:

"How would you mine an asteroid?" is frequently the principal question asked by those considering Planetary Resources' bold operation. In earthbound mining forms, a lot of data must be gained about the mineral body before itemized "mine planning" can start. On Earth, we have the benefit of thousands of long periods of history in mining assets; from physical work to the most exceptional mechanized automated mining gear being used today. The conditions predominant in earthbound mining have not extended excessively far from their ancient roots—a gap in the ground, extending to a quarry or open pit, at that point at times into underground passages. The latest progression has been in the quest for earthbound assets from already distant areas. From this inexorably expensive interest, we have today extended to getting oil from off-shore ocean platforms boring far beneath the ocean bottom, gasses from the air, what's more, even now starting to secure minerals from the profound ocean bottom.

Recuperation and refining of materials in a microgravity situation will happen through significant research and development. Planetary Assets will lead to the formation of basic in situ extraction, what's more, handling advances giving access to both asteroidal water and metals. At the point when joined with our ultra-minimal effort profound space wayfarers, this speaks to an empowering ability for the maintainable improvement of space[3].

B) Space Commercialization:

The industrialization and settlement of space is probably going to be achieved principally by expanding business exercises in space, worth a few billion dollars for every year, including the accompanying existing exercises: telecommunications, direct broadcast TV, navigation (e.g., the Global Positioning System), remote detecting, and meteorological administrations. Low Earth Orbit (LEO) satellite constellations will generally twofold the yearly income of these administrations throughout the following decade[4].

C) Availability of Space Resources:

In space, the parameter which decides how simple or troublesome it is to convey mass starting with one orbit then onto the next, isn't distance, yet is the necessary velocity change, Δv, expected to execute the transfer.

From the thought of velocity increases for various transfers, it tends to be seen that it is simpler to go from low earth orbit (LEO) to about anyplace in the internal inner solar system than it is to get into space from the earth's surface.

Table 1: Mission Velocity Requirements (Δv)

Earth surface to LEO	8.0 km/s
Earth surface to escape velocity	11.2 km/s
Earth surface to GEO	11.8 km/s
LEO to escape velocity	3.2 km/s
LEO to Mars or Venus transfer orbit	3.7 km/s
LEO to GEO	3.5 km/s
LEO to HEEO	2.5 km/s
LEO to Moon landing	6.3 km/s
LEO to Near Earth Asteroid	approx. 5.5 km/s
Lunar surface to LEO (with aerobraking)	2.4 km/s
NEA orbits to Earth transfer	approx. 1.0 km/s
LEO to Phobos / Deimos	7.0 to 8.0 km/s

Likely low Δv focuses for starting asset development are the "Earth-Approaching" Apollo, Amor, or Aten type asteroids; the moons of Mars, Phobos and Deimos; the asteroid 1990MB Eureka, which is a Mars Trojan; any Earth-Trojan asteroid (1986TO being the main such found); any of the Earth-orbit-hugging "Arjunas"; and the Moon itself. (Trojan asteroids are bodies which share a similar orbit as a significant planet, are gravitationally caught in that orbit, and lead or slack the planet by 60 degrees in its orbit around the Sun.)[4]

D) In-SITU Propellent Production:

The mission velocity Δv expected to come to these "near earth" low Δv targets is not essentially more noteworthy than that expected to put a communication satellite in geosynchronous earth orbit (GEO). The Δv required to return material from these targets is in some cases very much less as that required to lift mass into orbit from the outside of the earth, and it doesn't really need to be given indiscreetly. It tends to be bestowed progressively, more than half a month, in this way significantly diminishing the requests on the propulsion/power system.

On the off chance that the arrival move can be practiced utilizing some portion of the recovered non-terrestrial mass as reaction mass, or fuel, and solar vitality for the power source, or installed nuclear power, at that point it gets conceivable to come back to earth orbit particularly more mass than the outbound-leg earth-orbitdeparture mass of the mining-processing spacecraft. Mass augmentation factors over 100 must be the underlying point.

The impact of the extremely low vitality necessity to restore some asteroidal material to earth orbit, together with the chance of utilizing asteroid determined mass for impetus, is that some asteroidal material might have the option to be conveyed into Earth circle for a cost which is particularly not exactly the expense to dispatch a similar mass of material from the Earth[4].

II. TRAJECTORIES AND POPULATION

Near-Earth Objects (NEO) are those galactic bodies whose orbit around sun converges with earth's orbit. The objects orbitwith their perihelion q < 1.3 AU and aphelion q > 0.983 AU[5]. Their orbit, for the most part, lies in the zone among Mars and Venus while converging Earth's orbit. Some NEOs are probably going to be ricocheted from asteroid belt because of gravity reverberation by Jupiter and Saturn and 'Yarkovsky impact', while scarcely any questions are accepted to be cometary origin[5]. The Yarkovsky impact is the sunward pull of any galactic body which happens because of the ingestion of anisotropic re-radiation of photons on the sunward side and re-radiation of infra radiation on the inverse body[6].

Table 2: NEA discover statistics

NEA Size	>1 km	>140 m	All Sizes
Discovered Population	875	8537	16,188 (H< 33.2)
Estimated Total	920 ± 10	27,116 ± 2206	413 ± 100 million (H< 30.0)
Discovered in 2016	7	568	1889
Discovered in 2015	9	527	1572
Discovered in 2014	12	507	1477

Truly, the NEOs are delegated Apollo, Amor and Aten class with limitations of a < 5.2AU. Michel et al[7] propose "inward Earth orbits" which expresses that objects which orbit totally inside of the earth instead of inside the earth. In this manner, right now, asteroids will be alluded to as "Anon" (shortened form of 'Unknown') [5].

Amor class asteroids are exceptionally discretionary and orbits in the zone among earth and mars on time size of millions of years with an enormous populace of Mars crossing objects. These asteroids have current age perihelion 1.017< q < 1.3 as appeared in a figure (1), while Apollo/Aten class asteroids are earth crossing objects with a high factor of impact.

The significant point to recall is that NEOs are dynamic bodies where persistent taking care of new articles into the near-earth zone happens from the fundamental Asteroid belt populace, just as some from Jupiter family comets, while barely any objects few are lost from this region because of impacts with the inward planet or different NEOs or are attracted towards the sun. The habitation of the new articles to enter the near-earth region shifts on the timescale of $10^5 – 10^7$ years and this recurrence of the effects similarly concerns the lives on Earth[5]. (Bottle et al. 2000) claims that 64% of NEOs start from the inner main asteroid belt, 24% originate from the focal asteroidal belt and 8% from the outer asteroid belt.

Krasinsky[8]utilized gravity bother on mars utilizing high accuracy estimation instruments on Viking and Pathfinder rocket to appraise the total mass of objects in the main asteroid belt, with an opposite force relationship N(>D[km])= CD-b, where C= constant (equivalent to 942), N= no. of object of diameter (D) more noteworthy than a kilometer. His asserted to around 3.6×10^{18} t or about 5% of total moon mass. The size of items ranges from grains to minor size planets. Around 1 to 2 million articles are more noteworthy than 1 km (0.6 mi) diameter, and Ceres, Pallas, and Vesta with adiameter of 952, 544 and 529 km respectively[6]

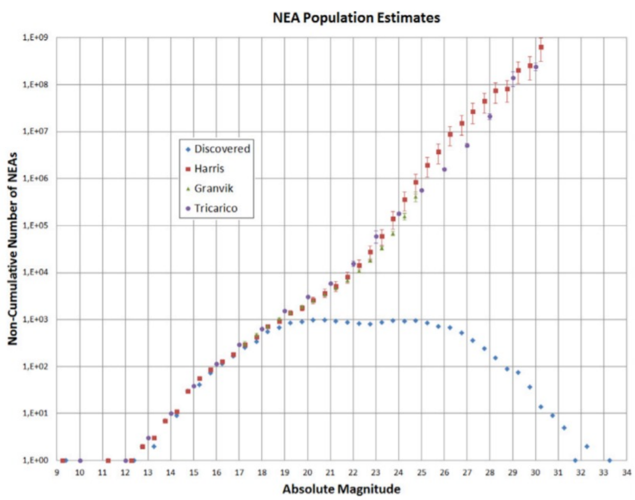

Figure 1: NEA population graphical statistics of discovered NEA and estimated NEA

The figure (1) portrays a model of comparison between discovered NEOs and assessed populace. The graph shows the uniqueness contrast with a magnitude more prominent than 19, for example under 570m in diameter. In recent years, the no. of discoveries of new NEA have been expanding with the advancement in the detection method. Table (2) shows the present populace of discovered NEA with respective diameters. It is seen that the detection rate stays 1500 every year. The investigation estimates that about 94% of an asteroid with diameter more prominent than 1 km are identified, while, about 29% of NEAs with breadth more noteworthy than 140 m have been found. The asteroids with a diameter between 10 to 50 m, around 4600 NEAs from a total evaluated populace of 29 million have been found.

III. MINERALOGY AND COMPOSITION

A nitty gritty examination and investigation of meteorites give a huge database of chemical makeup and genesis of asteroids. The arrangement of physical qualities, synthetic structure, and geographical highlights are derived from chemical analysis of meteorites, ground-based perceptions, satellite imaging and spectral reflectivity investigation of asteroids at ultraviolet, visible and near-infrared wavelength by NASA's, ESA's and JAXA's profound space unmanned mission[9].Various spectroscopic examination and photometric investigation have characterized wide varieties of NEA composition made up of nickel-iron, silicates and bituminous[10].

Till now, all suspicions on the makeup of asteroid just rely upon ground-based observations and spectroscopic imaging and suggested groupings with the data-base dependent on meteorite study. The information acquired from the meteorite is just the "ground truth" available.

So as to survey asteroidal mineralogy, it is important to examine the meteorite mineralogy and characterization.

A) Meteorite Mineralogy:

For the most part, meteorites are delegated Stones, Stone-irons, and irons as appeared in fig.(2)

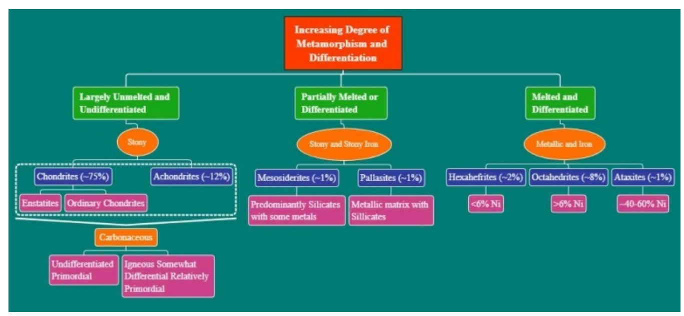

Figure 2: Generalized Asteroid Classification

The stones are additionally named as the Chondrites and the Achondrites. They are to a great extent un-liquefied and undifferentiated, and thus compositionally unaltered from the starting point of the solar system. The Chondrites are considered as primitive bodies with almost zero to low transformative nature and with the least aqueous adjustment and metasomatism. These are additionally delegated Enstatites, Ordinary Chondrites, and Carbonaceous Chondrite. The Achondrites are molten, basaltic and can be effortlessly separated as “un-liquefied” by perceptions and are subclassified as an eucrite, ureilite, aubrite, and lunar and Martian (SNC)[10].

The stony-irons are intensely separated and make nearly 1% of all falls with subclassified as hexahedrites and pallasite[9]. The metal and iron contain 1% of absolute falls and comprise hexahedrites, octahedrite, and Ni-rich ataxites. These are accepted to be sections of the metallic core of protoplanets and separated during an interruption in a cataclysmic effect[9][10].

B) Asteroid Mineralogy:

Based on chemical composition and spectroscopic examination, the NEAs can be ordered into 3 classifications: C-type (carbonaceous chondrites) S-type (stony) and M-type (metallic) asteroids.

An investigation expresses that about portion of the number of inhabitants in NEA includes C-type (carbonaceous) asteroids for example wealthy in carbon and water. The remaining can be assessed as S-type and M – type asteroids with a rough composition of 20% metallic iron-nickel composite, approx. 6% of ferrous sulfide mater troilite and a huge measure of olivine, pyroxene, and plagioclase feldspar.

The mineralogical chemical and physical have appeared in the table (3).

Table 3: Chemical and physical properties of minerals

Type	Mineral	C2-type** (wt. %)	C1-type (wt. %)	S-type (wt. %)	M-type (wt. %)	Lunar Regolith
Free metals	Fe	10.7	0.1	6 – 9	88	0.1
	Ni	1.4	–	1 – 2	10	–
	Co	0.11	–	0.1	0.5	–
Volatiles	C	1.4	1.9 – 3.0	3	0.1 – 23	0.014
	H_2O	5.7	12	0.15	2.6	0.045
	S	1.3	2	1.5	~0.1 – 7	0.12
Mineral oxides	FeO	15.4	22	10	3 – 15	15.8
	SiO_2	33.8	28	38	21 – 54	42.5
	MgO	23.8	20	24	5.9 – 31.9	8.2
	Al_2O_3	2.4	2.1	2.1	1.4 – 10.6	13.8
	Na_2O	0.55	0.3	0.9	0.12 – 1.8	0.44
	K_2O	0.04	0.04	0.1	0.01 - 0.22	0.15
	P_2O_5	0.28	0.23	0.28	0.03 – 1.39	0.12
	CaO	1.15 – 2.0	1.36	3.36 – 11.0	1.09 – 8.12	12.1
	TiO_2	0.11 – 0.13	0.07	0.31 – 1.23	0.11 – 0.77	7.7
Physical properties	Density(g/cm^3)	3.3	2.0 -2.8	3.5 - 3.8	7.0-7.8	1.5-1.9

The C-type (carbonaceous) asteroids form the greater part of near-Earth planetary bodies. The carbonaceous chondrites are named along these lines, in light of little minor rounded grains of silicate material known as "chondrules" implanted into the surface. The C type asteroid is made out of carbonaceous material, water, phyllosilicates, oxides, sulfides including iron, magnesium, and calcium present. The composition of C type asteroid has the equivalent unaltered substance that was framed during solar nebula even before our solar system appeared. These sorts of asteroids have a lower composition of hydrogen and helium gases. The phyllosilicates present are like enduring molten feldspathic rock as far as composition and structure[9].These kinds of asteroids are wealthy in materials for life support and operations. The primary factor of this C-type asteroid is that the vast majority of the substance for example carbonaceous material, clay and water is accessible in hydrated form. Water exists in both free and chemical forms and includes up to 30% of the complete mass. The carbonaceous material likewise makes up to 30% of the complete substance. The carbonaceous chondrites are subdivided into 5 classes:

1) C1 carbonaceous chondrites are comprised of 10% hydrated clay mineral, 2% to 5% carbon as graphite, hydrocarbon and natural compound, 5% to 15% magnetite and sulfur content, iron sulfide, and other water solvent sulfide form.

2) C2 carbonaceous chondrite comprise 10% dissolvable sodium and magnesium salts, 2% to 10% of magnetite and minimal lesser water and sulfur content.

3) C3, C4, C5 carbonaceous chondrite are poor in water, carbon and sulfur yet have comparable physical highlights like C2 and C3 type[1].

The S-type (stone) asteroids make up to 15%-17% of the known NEA population. These are made out of mafic, siliceous and rocks. The S-type asteroids are transformed yet unmelted and have low rate arrangement of carbonaceous and unstable substance and consequently have a high level of separation when contrasted with C-type asteroids. For the most part, the material piece includes both C-type and M-type class asteroids. The structure of S-type asteroids incorporates oxides of iron, nickel and magnesium silicates with olivine and pyroxene mineral in like manner. The asteroidal components, for the most part, comprise platinum bunch metals and rare earth elements.

The M-type (metallic) asteroids are accepted to be parts of fractured ore ejected from protoplanets during an effect by different objects. The parent M-type asteroids extended from 20-200 km in diameter. These metallic asteroids are made out of 10% to 60% of non-oxidized iron, nickel and cobalt and some rocky materials. The piece of rocky materials differs from zero to practically rough for example like S-type asteroids. These sorts of asteroids, for the most part, contain a high piece of auxiliary steel, including platinum group metals and rare earth metals as appeared in the table above[10].

IV. GEOLOGICAL CHARACTERIZATION OF ASTEROID

There have existed observational techniques for the galaxies for a long time and even hundreds of years. Notwithstanding, asteroids have for some time been an understudied heavenly wonder; there were no adequate strategies or innovation around that would carry out the responsibility appropriately. It was, as indicated by Kowal, not until just about 1970 when singular asteroids could be analyzed in an increasingly explicit issue, for example, shape, size, and composition through remote sensing systems. Presently the asteroids are, for example, a significant part of the unsolved mysteries about the cause of our solar system. Furthermore, exact perceptions could be a method for tackling them. Through observing asteroids utilizing current techniques portrayed right now; can be deciphered to pick up information on the orbital situation of an asteroid, the variety in texture of its surface, its shape, and even rotation. By picking up data on these highlights and setting it into the background with encompassing asteroids, it is conceivable to perform factual examinations that could improve our insight into the asteroids' advancement and origin of our solar system[11].

As per scientist Harris and Drube, there is both proof and logical reasoning behind the relationship between the ordered kind and composition of an asteroid and its denseness and porosity - C-type asteroids are less sturdy than siliceous S-and metallic M-types (see table 4). There are significant factors to consider while evaluating the material science and hence the value of any NEO, and these characterizations streamline the speculation and documentation of asteroids. These are the primary three sorts pertinent for this theory; in any case, there are different sorts and subtypes existing for different circumstances[12].

Table 4: Chemical Composition and Resources of Asteroids

Asteroid Type	Chemical Composition	Resources	Additional Info
C-type (carbonaceous)	Clay and silicate rocks.	Water, other volatiles and carbonaceous compounds.	Generally common. Farthest away from the sun; generally antiquated and saved because of low temperatures. Some assessed to contain up to 22% water because of failing to reach above 50°C. Different volatiles could be utilized for metallurgy, horticulture and air production.
S-type (siliceous)	Mostly stony materials (e.g. olivine, pyroxene) and nickel-iron metals.	Rocks, Nickel and Iron.	Existing generally in the inward part of the Main Asteroid Belt and numerous NEO's have a place with this sort. Accepted to be the wellspring of the most usually discovered chondrite meteorite.
M-type (metallic)	Primarily metal. Trace silicates.	Nickel, Iron, PGM's, Cobalt, Gold,	Additionally, called X-type. Accepted to be remainders from bigger >100km asteroids, leaving just the amazingly thick metal cores after enormous crashes at the beginning of the solar system. Found in the central locale of the Asteroid Belt.

These variables likewise affect any theoretical effect by asteroid on Earth, since it has been inferred that the fundamental sturdiness of impactors, for example, asteroids or meteorites firmly decides their casualty. Airbursts, for example, Chelyabinsk and Tunguska - where the last really thumped down trees over a region of 2000 km2, despite the fact that it never arrived at the ground are aftereffects of an increasingly permeable material while a progressively metallic body with comparable size could arrive at the ground with destroying results, for example, at Barringer Crater in Arizona[12]. Through top notch remote detecting combined with proper counter-quantifies, a fiasco through effect of an asteroid could be maintained a strategic distance from. This gives an extra motivation to help the investigation of space and research of astronomical bodies.

Therefore, remote detecting strategies with high exactness are of high significance in any event, for different reasons than conservative or research related ones - they would one be able to day, through exact perceptions, perhaps help forestall a cataclysmic event of huge greatness.

A few remote sensing strategies are utilized autonomously or consolidated to pinpoint the asteroids generally inclined to contain important material. The most widely recognized systems will be portrayed right now, most seasoned and generally fundamental to more current and further developed. As per resources[13], the optical telescopes choose the spin rate and size, the radar decides the 3-dimensional shape and IR telescopes decide albedo and refines the kind of asteroid. From that point forward, the excursion to investigate and extract the minerals can start.

A) Spectrophotometry:

Photometry is a procedure for just estimating the brightness of an Asteroid. It is fundamentally done through collecting light in a telescope, preparing it through certain filters and afterward capturing and recording the light. The perceptions are standardized through standard system to make exact examinations conceivable. This is a pertinent method for assessing an asteroid's physical formation, since there is absence of atmosphere which could influence the outcomes with their own reflectance. In beginning times, real photographic and visual methods were utilized. These are in present day times supplanted with electronic techniques, for example, a photoelectric photometer, which measure the light intensity of an object by applying its light discharge onto a photosensitive cell[14]. The latest innovation is called Charge-Coupled Devices - progressively known as CCD cameras. These work through concurrent correlation of the object of intrigue and a few neighboring field stars as reference in a two-dimensional picture. Different filters can be applied for dissecting distinctive spectra of intrigue. On the off chance that numerous filters are applied in progression to make an integrated outcome, the subsequent phantom examination is like that of spectrophotometry.

In the event that the light mirrored from an asteroid is approximated at numerous wavelengths and accordingly contrasted and the shade of sunlight, this can allow important data on what material the outside of the asteroid is made out of, which thusly is a solid sign of what the asteroid is commonly made out of. The outcome is contrasted and reflectance from known kinds of rocks and minerals. These are the essential standards of spectrophotometry[15].

B) Radiometry:

As per Kowal radiometry is commonly the procedure for estimating infrared radiation from an asteroid. Similarly, as when the Earth is struck by sun-oriented radiation, some is reflected and a bigger segment is consumed. The assimilated vitality is discharged as long wave radiation which can be estimated in the IR range (see fig 3). The measure of thought about radiation is reliant the asteroid's size and albedo. Consequently, if the occurrence daylight is known, contrasting the produced IR radiation and measure of sunlight reflected from the surface can give an estimation of the asteroid's albedo. When having decided the splendor, separation and albedo, and evaluating the temperature dissemination, the size of the asteroid may be processed[16].

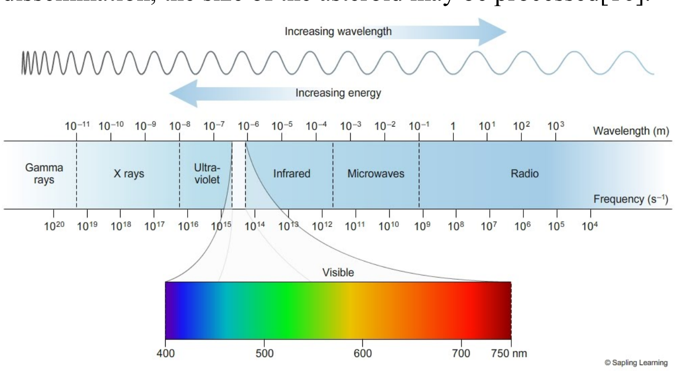

Figure 3: An image showing the different wavelengths of the electromagnetic spectrum. Radiometry is measured in the infrared part of the spectrum. Credits:chempendix/em-spectrum.

In any case, a few suppositions about the asteroid material must be made ahead of time, for this procedure to be compelling. This is because of the way that the warmth dissemination varies between different sorts of asteroids, since for example metal is a superior heat transmitter and warms up more consistently. Indeed, even turning pace of the asteroid matters, since the time the surface is in the shadows decides the coolness of the asteroid and in this manner the warmth emanation also. The shape likewise adds to specific varieties in heat discharge signatures. By and by, these blunders can all in all be accounted and made up for, giving a minor 10-15 % error while assessing the distance across of an asteroid, which has been controlled through polarimetry and direct perceptions during stellar occultations[11].

Radiometric alignment comprises in connecting pixels forces to a physical parameter. Its primary objective is to permit correlations of spectra from various starting points and furthermore estimations of significant physical parameters. This activity is exceptionally significant since the motion appropriation in the raw spectrum is totally different from what has been transmitted by the observed object. It will be recalled that the optical signal experienced a few filters, in particular that of the ambience, of the equipment, of the CCD's quantum productivity.

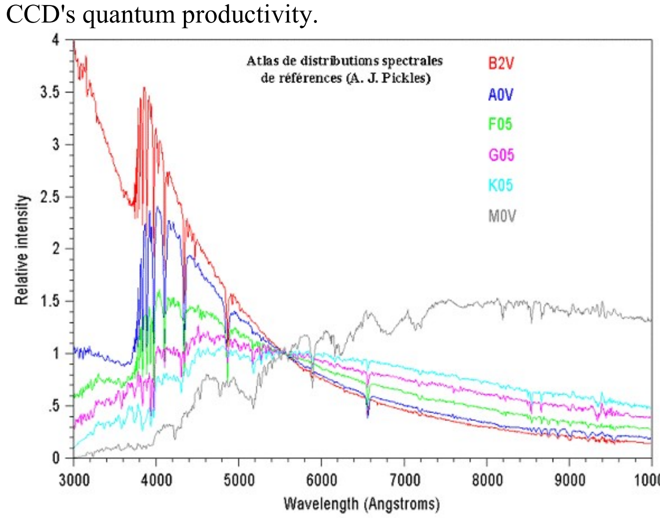

Figure 4: Spectral analysis

The tasks comprise in the assurance of the equipment's spectral reaction by examination of the observed spectrum with a reference range for the article under investigation. By isolating one range by the other, a sort of "flat field" is acquired that can be utilized for radiometric scaling of the remainder of the recorded information. The accompanying figure (4) shows a few reference spectra for random spectra types.

C) Hyperspectral Imaging:

As indicated by Prakash Chauhan, sampling of a spectral scope of enthusiasm with a couple of expansive channels just is the essential constraining component of the multi-spectral sensor systems, which seriously influences recognizable proof of mineral species and quantitative mineralogical evaluation. Hyperspectral imaging is like other electromagnetic observations, despite the fact that it contrasts by utilizing a tremendous measure of minor spectra - regularly several restricted constant otherworldly groups - bringing about increasingly calibrated spectral reflectance information from the UV-VIS-NIR region. The objective of hyperspectral imaging is to "acquire the range for every pixel in the picture of a objects, to discover objects, distinguishing materials, or recognizing forms[17]."

Subsequently, when utilizing this strategy, data about everything about and structure can be extricated with high precision contrasted with the multispectral system.

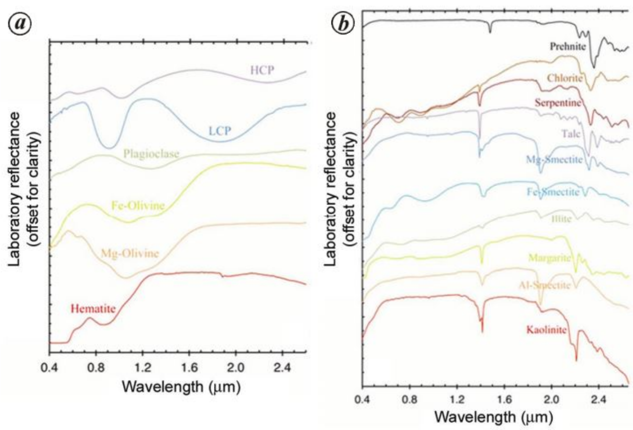

Figure 5:Reflectance spectra of (a) common rock forming minerals and (b) water-bearing minerals formed as analteration product on Mars. Figure adopted from Viviano-Beck et al.[18]

Whenever plotted against frequency, the reflectance esteems show a spectral reflectance bend (ref. fig 5). Right now, progress metal particles, for example, Fe2+, Fe3+, Mg2+ and so on., are shown as changes in the NIR region (ca 0,7-2,6 μm) and silicates, salts and water bearing minerals are shown in the mid-and warm infrared areas of the electromagnetic continuum[17].

D) Thermal Modeling:

The warmth impression of an obscure object in space can educate a great deal concerning it. By estimating certain parameters through thermal imaging, valuable data can be separated from the examination. To acquire high-exactness information on near-Earth asteroids it has become regular practice to utilize thermal models. These models are ordinarily founded on IR perceptions from main belt asteroids. Be that as it may, since NEA will in general have progressively unpredictable shapes and are regularly seen at bigger solar phase angles, the models have been experimentally assessed and adjusted for NEA's by Harris[19].

This NEA Thermal Prototype (NEATM) depends on spherical geometry and can generate the diameter and albedo of essentially any atmosphere-less body from thermal IR information[12]. The prototype is an expansion to the thermal prototype idea portrayed by Lebofsky et al[20]. The new prototype joins a fitting parameter (truly called radiating parameter) which takes both thermal abeyance, spin vector, and area roughness into account.

On the off chance that the asteroid has a rugged area, the subsolar temperature is higher than anticipated with a smooth area. This happens due to the "radiating" impact, for example improved re-discharge of light from area components that are confronting the Sun[12]. This parameter of area ruggedness could be demonstrated by adding hemispherical craters to the area[21].

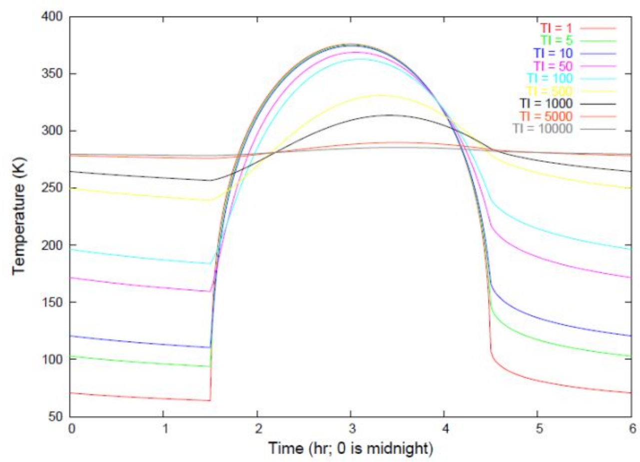

Figure 6:The thermal inertia: smoothing of the surface temperature distribution as a function of time. Different objects give different thermal inertia (TI) presented to the right. Image adopted from Matter et al.[21].

Harris and Drube[12] express that "the best-fit η esteem is a proportion of the evacuation of an asteroid's temperature appropriation from that of an object with a smooth surface and zero thermal abeyance, or zero spin, in thermal balance with insolation (in which case $\eta = 1$). " The best-fit η values from the NEATM could be utilized to appraise thermal abeyance, where the estimation of Γ (thermal abeyance) depends on the augmentation of thermal conductivity (c), density (ρ) and specific heat of the material (κ). Thermal abeyance could be characterized as a proportion of the obstruction of a material to a temperature, along these lines influencing the smoothingof the surface temperature conveyance (ref. fig 6).It is conversely related to asteroid size[21].

Matter et al.[22]have directed the first thermophysical model (TPM) for examination of interferometric (data from superimposed electromagnetic waves) perceptions of asteroids. Thermal IR information was achieved with the Mid-Infrared Interferometric Instrument (MIDI) and the Very Large Telescope Interferometer (VLTI) at the European Southern Observatory (ESO). The asteroid Daphne was utilized for examination. The model they utilized was assessed to give an efficient vulnerability of 4 and 7% separately, for the asteroid volume estimation, contingent upon variety of the strategy utilized. The TPM investigation demonstrated a surface thermalabeyance inferred to be smaller than 50 J m−2 s−0.5 K−1 and moderate plainly visible surface ruggedness.

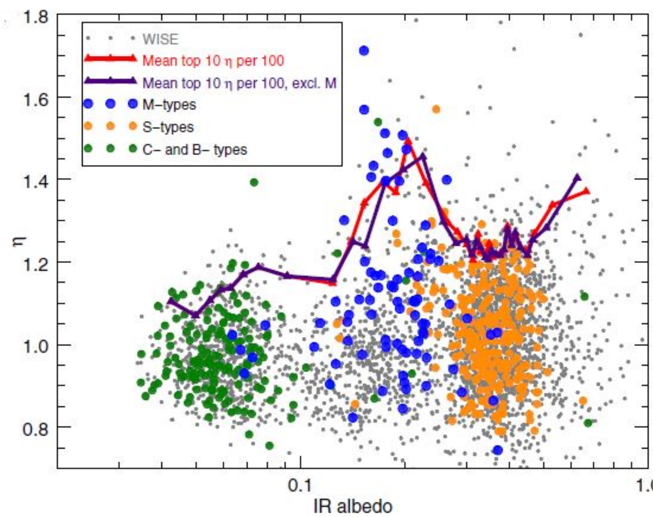

Figure 7: From WISE (Wide-field Infrared Survey Explorer (NASA 2015)) data. Points are η values versus infrared albedo for main-belt asteroids. Colored bullets represent taxonomy types. The red curve is a plot of the mean of the highest 10 η values in bins of 100 data points; the purple curve is the same excluding M types. Points with fractional uncertainties in η and IR exceeding 20% have been removed. Image adopted from Harris and Drube[12].

In the event that anasteroid has encountered transformative nature, fluid adjustment or dissolving, they will as per McSween Jr et al.[23]differ as far as thermal development. Their individual thermalimpressions could be concentrated to study the protecting impact of regolith (heterogeneous envelope of rocks, dust and so forth on solidrock), the buffering impact of ice and liquid flow and how heat conveyance changes because of separation. A connection between asteroidal pinnacle temperature and heliocentric separation can likewise be determined through thermal models. The utilization of other warmth sources than the Sun, for example, electromagnetic acceptance and concussions, have been regarded adequate enough just for basic counts of credibility. Besides, if a NEA gives indications of heterogeneity it could be broke down through both spectral reflectance information and the NEATM to give a reasonable estimation to whether the asteroid is just wealthy in assets on a superficial level or in the center too. Harris and Drube[12]likewise bring up that perhaps metal-rich up-aspirants ought to be exposed to encourage optical, thermal infrared and radar perceptions, just as TPM to accomplish the most exact estimations. In any case, to date2014 no methodical examination had at this point been completed of the capability of η, as inferred by NEATM model fitting, as a tracer of metal substance in asteroids[12]. A case of various η values contrasted with IR albedos of different asteroid types are introduced in figure (7).

V. MINING OPERATION

Carrying out mining activities in space is a critical task. The resources on the asteroid are also becoming a major focus for many space agencies and commercial entities. An ideal NEA could provide multitude of resources in massive quantity. This could serve as a backbone for future celestial mining companies. According to Reuters' interview with Planetary resources, a 30 m long NEA can hold platinum worth US $50 billion[24]. The resources are the main focus, the process to execute mining operations is critical. It requires a proper functioning process: prospect, capture, extract, process and store the product. The figure 1 shows the hypothetical mission architecture which includes important elements and processes for asteroid mining.

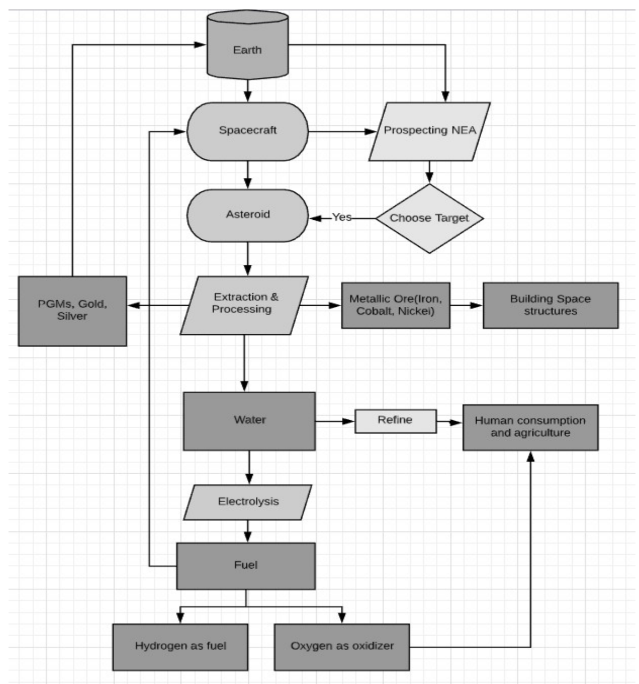

Figure 8: Asteroid Mining operation architecture for hypothetical future mission

A) Capture & Landing:

To perform mining operations in zero gravity conditions, it is necessary to anchor spacecraft safely. The spacecraft can be easily anchored if the surface is rigid, competent and strongly bonded using pitons, adhere to surface or clamp over the surface. But this may get challenging with low strength regolith surface. Here, it is required to anchor over a wide area or wrap completely using ropes or net. The asteroid can be anchored using the following methods:

Table 5: Potential options for anchoring spacecraft to target asteroids[10].

Methods	Application
Nets, ropes	Tie down the spacecraft around the NEA
Drive-in-pitons	Assuming the surface is rigid, it can be clamped against resisting surface
Harpoons or penetrators	Fire harpoons, once locked can resist extraction
Large Anchors	Fluked anchors would hold against opposing surface
Contra-rotating screws	If the regolith is loose enough, it would be possible to borrow the screw
Adhere the surface	Adhering would cling the spacecraft over the surface
Magnetic docking	Only applicable if the asteroid is M-type (metallic) asteroid

B) Extraction& Processing:

The concept of Asteroid Mining was first proposed in 1989 in the novel "Edison's Conquest of Mars"[25]. Till now, many asteroidal mining concepts, roadmaps, systems and design architecture have been put forward. In 2013, NASA's NIAC study developed an architecture on resource accessibility, economic feasibility, mission architecture, spacecraft design i.e. Robotic Asteroid Prospector (RAP) and reviewing various mining technologies. According to it, the three main resources on NEA are Water, Platinum Group Metals (PGM) and bulk regolith[26].

The bulk regolith would be used in space manufacturing i.e. construction of large infrastructures and as a radiation shielding materials. The PGM materials are likely to be sold to Earth clients. The water would serve multiple purposes: life support, fuel, radiation shielding and agriculture. Once refined and processed it could be used for human consumption i.e. drinking and breathing (oxygen separated by electrolysis of water). Numerous technologies have been tested for increasing the efficiency of the system and has already reached an efficiency of 90% -95% till now. The hydrogen and oxygen separated from electrolyzed water can serve as high energy propulsion purposes i.e. high combustion (LOX/LH2) propulsion or solar thermal propulsion. The company Tethers Unlimited Incorporated has developed a CubeSat thruster named "HYDROS Thruster" which produces a thrust over 1.5 N and a specific impulse of 310s[27].

a) Excavation:

The mining method significantly depends on the physical properties of the asteroid. Mining in microgravity condition would require positive anchoring which would provide necessary grip against the rocky surface. The reaction force generated would require anchoring points over a wide area. The mining method would vary from regolith to solid rock; different again for volatiles and frozen ice. For loose regolith, scoops, scraper or shovel method would work, whereas hard rock will require drilling, cutting or blasting. The friable but bound material to be cut or broken before collection. Frozen volatiles may be low heated and collected. Metallic rocks would require cutting and high melting or reacting it before. Table (6) describes the mining methods for different mining conditions[10].

The execution of mining operations would require a deep understanding of the physical properties and characteristics of the surface. Depending on various factors, various mining operations will vary.

Table 6: A table showing different extraction techniques for different types of surface[28].

Asteroid type	Extraction techniques
Volatiles	Blast, rip
Ice mixtures	Blast, heat, distil
Elemental metals (primarily Ni-Fe)	Concurrent with processing
Hard rock	Blast, disc cutters
Hard rock-metallic Ni-Fe	Blast, heat, rip

i] Surface Mining:

Mining on the surface of an asteroid appears challenging because of (i) very low regolith strength (ii) zero gravity conditions (iii) containment. In 1984, Gertsch had proposed a classical three-drum Slusher/ scraper for lunar mining because of its simple mining and low mass design. But none of this appears to be applicable for asteroid mining because of low strength regolith and zero gravity[29].

Thus, it is necessary to (i) to ensure that scraper or shovel are deeply anchored against the rock and (ii)collected materials are enclosed within the machine or else it will "float away" e.g.: screw conveyor or enclosed drag chain or clamp-shell hydraulic grab[10].

ii) Underground Mining:

Underground mining would provide an advantage for extraction on asteroids as well as on the moon. It will be easier to generate reaction force for mining techniques e.g.: cutting, drilling, dragging and can be depleted in the desired manner. It will also be easier to contain the crushed or which is cut material. Additionally, the "mined" volume can also be used for the construction of "underground infrastructure"e.g.: habitats, storage facilities or plant.

Mining on asteroids would require road-header type technology, which could shotcrete and seal the excavated tunnel border. The important factors to be considered while selecting mining technology is that it should require minimum consumables, it should not require a large reaction force and have minimum impact on the ground[1].

Note that these technologies are only feasible for mining "massive" amount of resources. In the situation of Earth-impact threat, they could be the primary choices for planting underground nuclear warheads, which could deflect or mitigate the body away from the Earth[10].

iii) In-situ Extraction:

In-situ extraction refers to fluid extraction using drill holes[30]. This technique is equivalent to the Frasch process where the melted liquid sulphur is extracted from deep deposits by injected steam, and solution mining using circulating solvents and salt deposits.This technique provides many benefits as it is simple and small mass equipment i.e. no mining, crushing, grinding, separation to worry. As there is no need for power to crush or grind, it seems to be less complicated and more efficient. On the other hand, this technique suffers critical risks like (i) loss of circulating fluid into the subsurface void (ii) risk of clogging of drill fluid return pathway due to fine sediments, clays, salts, waxes or reaction product. The pressurization of mining void could end up catastrophic fracture due to weak mantle to resist tensile force produced during pressurization[10].

b) Processing:

The physical state and accessibility of the resources are important factors for establishing processing units. The regolith on asteroids has low strength and high thermal inertia and low gravity than the moon. It is believed that micro impacts and regolith gardening can help in size segregation[26]. In 2014, researchers in Advanced Space Concept Lab in Glasgow suggest that solar radiation can be used to segregate grains by size. The constant force will accelerate small size particles to faster velocities than larger particles[31][32].

The processing technique will depend on the type of extracted material. Hence, these factors will be considered and the resource must be extracted, size segregated and then processed. Table (7) summarizes ISRU methods for processing resources.

Table 7: Different processing method based on the type of extracted resources[33].

Possible available resources	Methods to extract Resources
Volatiles (single compound of hydrogen, oxygen, carbon, sulphur and nitrogen) Rarely nitrogen, halogen and noble gases	Heating: Microwave or solar thermal process
Water (primarily from hydrated minerals)	A. Heating: Microwave or solar thermal process B. Ionic Liquid Acid Dissolution C. H_2SO_4 or HF dissolution
Metal oxides (for oxygen)	A. Ionic Liquid Acid Dissolution B. H_2SO_4 or HF dissolution C. Hydrogen Reduction D. Carbothermal Reduction E. Molten Oxide Electrolysis
Metal Oxides (for metal)	A. Molten Oxide Electrolysis B. Ionic Liquid Acid Dissolution followed by electrolysis
Elemental Metals (primarily iron, nickel)	A. Heating: Microwave or solar thermal process B. Molten Oxide Electrolysis C. Ionic Liquid Acid Dissolution followed by electrolysis
Platinum Group Metals (PGMs)	A. Heating: Microwave or solar thermal process B. Molten Oxide Electrolysis C. Ionic Liquid Acid Dissolution followed by electrolysis
Metal Oxides (oxygen and metal)	A. Molten Oxide Electrolysis B. Ionic Liquid Acid Dissolution followed by electrolysis

VI. BUSINESS CASE ANALYSIS

Investing resources into space endeavors could be viewed as an extraordinary risk, particularly when so much is as yet obscure and is being looked into right now. In any case, when present day "gold rushes" happened, they apparently don't occur on safe ground with known components and assets – they occur on new and mostly obscure territories with some level of risk included, as with the torrential slide like development of the web and related businesses[34]. Be that as it may, the space business is a genuine one with aggressive individuals and plans; Planetary Resources, for exemplification, is sponsored by individuals, for example, Google officials Larry Page and Eric Schmidt, movie producer James Cameron and Charles Simonyi, an early supervisor at Microsoft Corp. what's more, presently CEO at Intentional Software and many more.

Business visionaries with fortunes from the last "gold rush" - the computer and web upheavals - are presently putting resources into space, as indicated by Erickson[35]. The opportunities for regular citizens to bear the cost of space goes sooner rather than later is pulling in numerous financial specialists, and joined with new thoughts of promoting, for example, crowdfunding, as PR did while offering a photograph of yourself taken by the principal freely available space telescope[36], and the open source idea proposed by Johannsson et al. (2015), the entire venture is an open undertaking where anybody could contribute and be a part of mankind's next conceivable change in perspective. In March 2016 Eric Anderson, fellow benefactor and co-director of PR, said to CNBC that they are intending to have their first mining strategic 10 years[37]. For individuals to contribute, nonetheless, a significant level of feasibility and evaluated benefit is significant.

The cost estimation is utilized to play out a financial bring investigation back. Right now, think about the masscreation of the shuttle depictedexcluding the payload is $64.8 million. At the point when a few of similar units are produced the economy of scale rule applies, for example the expense per unit is diminished. The expectation to learn curve information representing this effect is[38],

TotalLotCost = $T1\ N^{(1+\ln(S)/\ln(2))}$ ----(1)

where T1 = is the hypothetical first unit creation cost, barring programming and ground support hardware costs. N = is the amount (lot size), S = learning curve information incline in decimal form. Here, a slant of 0.85 is utilized for cost calculations, which is a reactionaryvaluation.

$$FirstYearCost = TotalLotCost + N_r C_r + C_s + C_g \qquad ----(2)$$

N_r are the quantity of SpaceX Falcon Heavy dispatch vehicles required, at an expense for each dispatch vehicle of C_r of $90 million[39]. We expect here that one single rocket can lift 144 rockets as per their beforehand assessed mass. Flight programming cost C_s is $27.5 million, and ground support gear is $4.3 million. We likewise accept, that a substantial launcher would have the option to place a few spacecrafts into a low earth orbit, comparing to its payload limit. To assess the cost of water conveyed to different orbits from earth, the least expensive accessible alternative of placing 1 kg in a specific orbit is thought off. Theimprovement in dispatch vehicles permits a lower cost for each [kg]. A review of the parameters considered for the estimations is given in Table 8.With the defined parameters, and applying the expectation to learning curve information in Eq. (1), financial return charts are developed. The vehicle cost of water to different orbits is examined to recognize feasible business cases. The results are shown in fig. 9.

Table 8: Parameters and assumptions for the economic return analysis

• Cost of production of first unit: $113.6 M (from SSCM total cost)	**• Annual operations cost: $5.7 M (average)**
• Cost of launcher: $90 M (Falcon Heavy to LEO).	• Cost for 1 kg in GTO: $7.5 K (Falcon-9 estimate)
• Annual operations cost: $5.7 M (average).	• Cost for 1 kg in GSO: $21.5 K (Proton-M estimate)
	• Cost for 1 kg in Cis-lunar space: $35 K

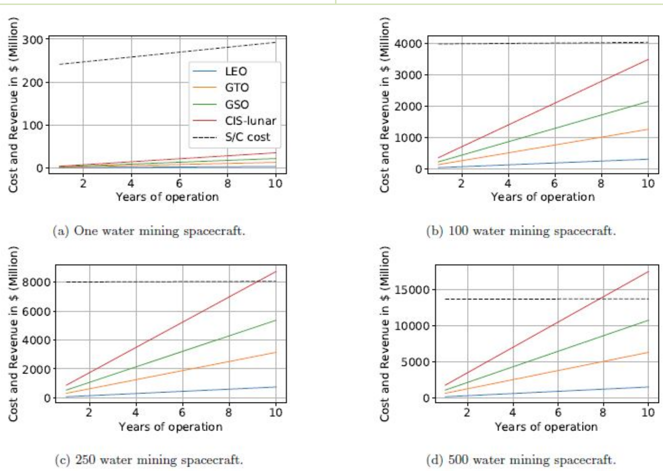

Figure 9:Cost analysis and economic return for (a) one, (b) 100, (c) 250, and (d) 500 spacecraft. The dashed black line indicates the spacecraft cost, including development, construction, launch, and annual operations cost. The revenue by sale and usage of the mined water is shown for LEO (blue line), GTO (orange line), GSO (green line), and Cis-lunar space (red line)[40].

Convincingly, the space business is as of now among the quickest developing ventures today.Its current incomes surpass around 250 billion dollars for each year, however a lot of this is associated with military defenses, communications, and weather forecasting. The space industry development will, as indicated by Dempsey, reflect the worldwide economy of things forthcoming[41].

VII. CONCLUSION

A brief analysis has been done in this paper on asteroid engineering, mainly emphasizing the discovery, investigation, redirection, and mining of near-Earth asteroids. A few concluding statements can be made here, as follows:

1. Current asteroid explored ideal models may not be adequate for recognizing the immense number of NEAs beneath 140m in measurement. There is a requirement for a noteworthy increment in subsidizing towards NEA disclosure, including reallocation of existing telescopes, just as building new ones, both on the ground and in space to expressly look for little NEAs, so as to in the long run consider our near space condition as "sheltered."
2. A key innovation of NEA redirection and additionally prospecting is the capacity to land and stay on a NEA. More research is required for creating vigorous landing mechanisms on obscure surfaces in low gravity conditions, which will prompt successively powerful redirection approaches, for example, tugboat, just as successively point by point prospecting of potential assets on NEAs.
3. The present comprehension of NEA arrangement is very constrained. The capacity to portray a NEA is right now for the most part constrained to remote perceptions of surface reflectivity. More flyby missions need to be led, at low expenses and quick improvement paces, to perform gravity mapping and study subsurface creation, so as to precisely depict what a NEA is made of.
4. Microgravity surface tasks is a rising subject of look into. While remarkable research has been done into creating rovers, penetrating mechanisms and enormous scope systems like earthly mining machines for use on the Moon and Mars, performing such activities in microgravity presents new difficulties that must be tended to explicitly.

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