Souvenirs from the Stars: Examining International Political Impacts of Space Mining

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Joshua Rauh Willoughby

Spring, 2022

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Bryn E. Seabrook, Department of Engineering and Society

Table of Contents

Extraterrestrial Mining and Society

While mining for resources already occurs beneath the surface of the earth, resource collection will likely also take place in outer space. Extraterrestrial mining, or "space mining," involves the harvesting of useful natural resources from celestial bodies. In the foreseeable future, mining targets include the moon, along with asteroids and meteors orbiting near Earth (May, 2021). A variety of exploitable resources exist on celestial bodies, both for usage back on Earth and in outer space (Gilbert, 2021; May, 2021). Despite the theoretical possibilities of space mining systems, the technology is accompanied by a difficult dilemma regarding international law. In 1967, the "Outer Space Treaty" was entered into force by the United Nations with signatures from nearly every nation in the world, including current leaders in space travel such as the United States, Russia, China, India, and nearly all of Europe (Arms Control Association, n.d.). The Outer Space Treaty is still in effect, and explicitly prohibits "national appropriation by claim of sovereignty, by means of use or occupation, or by any other means" with regards to objects in outer space. Although the Outer Space Act's verbiage was initially intended to ease Cold War military tension, it can also be interpreted as a major obstacle to implementation of extraterrestrial mining systems by both private companies and governments (May, 2021). Presently, there is a distinct lack of international discourse or agreement on the specifics of how space mining systems will be technically, as well as politically, implemented (Gilbert, 2021; May, 2021).

In the subsequent sections, space mining will be explored as a technological fix due to its potential disruptive effects on environmentally and socially impactful resource collection and utilization methods. Furthermore, space mining systems will be examined as political technologies due to their inevitable impact on domestic and, more drastically, international political relationships. As a whole, the following research will focus on investigating both the relation between space mining systems and the current societal and technological practices that they are poised to disrupt, along with the inherent international political influence of extraterrestrial mining applications. The Science, Technology, and Society (STS) concepts of the *technological fix* and *political technologies* will be used in this analysis to address both above research topics, respectively.

What is "Space Mining" and why is it Important?

As explained in the introduction, space mining is a conceptual practice that involves collecting, or "mining," useful resources from extraterrestrial bodies to be utilized by society. Due to limitations of current spacefaring technology, mining targets include the moon, as well as nearby asteroids and meteors. These present-day limitations are primarily unreasonable transit times to and from distant celestial bodies, making unmanned missions unviable economically and entirely preventing manned missions (May, 2021). Despite this current constraint, there is tangible interest in undertaking space mining missions from both international governments and the private sector. In 2020, NASA offered contracts to extract lunar rocks to several private companies by as late as 2024 (Gilbert, 2021). In 2019, Amazon and Blue Origin founder Jeff Bezos spoke of moving "heavy industry and mining" to outer space at a press event in Washington D.C. (Captain, 2019). Furthermore, nations such as China, Russia, Japan, and India, along with the European Space Agency, have expressed ambitions toward mining resources in outer space (Gilbert, 2021).

Although a variety of resources and materials are possessed by nearby extraterrestrial bodies, current developments are focused primarily on collecting water, minerals, rare earth metals, and helium-3 isotope (Keszthelyi, 2017; May, 2021). Unlike minerals, rare earth metals, and helium-3, water collected in outer space will likely remain in outer space, rather than be brought back to earth because of its unique chemical composition. Water molecules can be split into hydrogen and oxygen, from which hydrogen can be utilized as a major component of rocket fuel, allowing refueling of spacecraft thrusters while in orbit (Gilbert, 2021). Unsplit water molecules or oxygen are also useful as resources to be used in maintaining spacefaring technologies (May, 2021). Overall, mining for water is an effective way to reduce the weight and therefore increase the longevity of future rocket launches, reducing the amount of required rocket fuel. On the other hand, rare earth metals such as lanthanum, neodymium, and yttrium are extremely scarce on earth, despite being essential for widespread technologies such as smartphones and electric cars. Present-day practices for mining rare earth metals have been proven to be highly hazardous to both the environment and those involved in the mining process, who are often impoverished and underpaid (Lima et al., 2016). Finally, Helium-3 isotope is an element that has been theorized to be an efficient fuel for nuclear fusion and energy production, without emission of harmful radioactivity. While found to be present in soil on the moon's surface, helium-3 does not exist on earth (May, 2021).

Although space mining systems present a large number of resource collection possibilities, they also present a dilemma regarding international law. As mentioned in the introduction, the Outer Space Treaty of 1967, ratified by the United Nations with signatures from all current space-faring nations, contains verbiage that is particularly problematic for those hoping to collect and utilize resources from outer space. Although the treaty and its principles were put in to force during the heart of the space race with the major goal of easing military tensions between the United States and former Soviet Union, it also includes a principle that explicitly prohibits "claim of sovereignty, by means of use or occupation" of celestial bodies by any nation (Outer Space Treaty, 1967). While collection of resources is not specifically mentioned in the treaty, the forbiddance of ownership of celestial bodies by any nation, and subsequently private companies within a nation, is an obvious obstacle for the implementation of any space mining system. In 2015, however, the United States government attempted to circumvent this obstacle with the legislation of the U.S. Commercial Space Launch Competitiveness Act, or "Space Act." Within the text of the legislation, United States citizens and industries are encouraged to engage in "commercial recovery of space resources" and are "entitled to any asteroid resource or space resource obtained" (Space Act, 2015). Nowhere within the act, however, are the restrictions mentioned by the Outer Space Treaty discussed. In 2020, the United States would go on to draft the "Artemis Accords," currently signed by 12 nations, with the intent of promoting "peaceful exploration of deep space." These accords go on to explicitly state that the "extraction of space resources" is not violative of the Outer Space Treaty (Artemis Accords, 2020). Despite the presence of both the Artemis Accords and Space Act, however, there is no internationally agreed upon legislation regarding resource collection in outer space, and a distinct lack of international discourse on how this resource collection will be carried out.

Establishing STS Frameworks: Technological Fix and Political Technology

The topic of space mining technology fits well within an STS based analysis due to its potential for highly disruptive impacts on multiple facets of present-day society. Firstly, space mining systems are poised to disrupt a number of society's resource acquisition and utilization practices. In analyzing these disruptive effects through before-and-after comparison, the STS theory of the *technological fix* is highly appropriate. Secondly, space mining promises to present obstacles in international political discourse. The STS theory of *political technologies* is apt for analysis of these challenges.

Technological Fixes

The concept of the technological fix was first established by American nuclear physicist Alvin M. Weinberg, and later elaborated upon by Baylor University mechanical engineering professor Byron P. Newberry in the Encyclopedia of Science, Technology, and Ethics in 2005. Put simply by Newberry, a technological fix involves the development and implementation of technological systems to solve "social problems that are traditionally addressed via … social processes" (Newberry, 2005) In most literature, a technological fix is ascribed a negative connotation, however sociologist Amitai Etzioni has critiqued this perspective by suggesting that these pessimistic views are often based on conjecture or assumptions rather than hard evidence, and that technological *shortcuts* are not always detrimental (1968). Common examples of the technological fix framework's application can be seen in well-known examples such as prescription of psychotropic drugs to "fix" conditions such as ADHD, along with development of destructive weapons such as the atomic bomb as a means to deter war (Newberry, 2005; Weinberg, 1966). To better fit this research, the technological fix framework will be expanded to problems that are currently addressed by technological as well as social processes. In particular, the usage of space mining for fuel resupplying, collection of rare earth metal and ores, along with collection of helium-3 for increased nuclear power capability will be considered as a technological fix for present-day processes intended for the same goals.

Political Technologies

Established by political theorist and Science and Technology Studies Chair at Rensselaer Polytechnic Institute Langdon Winner in 1980, the theory of political technology encompasses the idea that "certain technologies in themselves have political properties." One method of possessing political properties given by Winner is being "strongly compatible with … political relationships" or correlating with particular kinds of political relationships (1980). A good example of inherently political technology given by Winner is the unusually low height of certain parkway bridges in Long Island, New York. As explained by Winner, these designs were intentional, with the social and political impact of preventing lower-income and African American citizens from reaching specific locations on public transport (1980). Winner, however, also details valid criticisms of his theory in his 1980 publication. According to Winner, it may also be contended that any political weight held by a technology is entirely within the control of society and can just as be easily given as taken away. For this research, space mining systems from different industries and nations will be analyzed through the lens of political technology, due to their inherent influence on domestic and, more drastically, international political relationships.

Research Objectives & Methodology

The following research focuses on investigating both the relation between space mining systems and the current societal and technological practices that they are poised to disrupt, along with the inherent international political impacts of extraterrestrial mining technology. This research is divided into two main categories, the first being an analysis of space mining applications using a *technological fix* STS framework, and the second being an analysis of the implications of space mining systems using a *political technologies* STS framework. Within each main category, research is divided into three subsections, corresponding to main topics of the category. The methodologies utilized in researching these topics include documentary research of space mining developments and capabilities, along with current terrestrial practices for gathering similar resources and developments in impacted areas. Additionally, this examination includes a policy analysis of both international law (See Outer Space Treaty, 1967; Artemis Accords, 2020) and United States domestic law (See Space Act, 2015). Finally, this research includes a discourse analysis involving educated perspectives on space and terrestrial resource acquisition practices along with policy critiques and opinions. Sources utilized in this research include primary sources such as original research in academic journals, government publications, and digitalized original publications of policy documents. Secondary source analysis of topics including space mining trends and impacted areas, along with policy are also included in the development of this research from sources such as reputable websites and news organizations.

Exploring Space Mining as a Technological Fix and Political Technology

Introduction

Extraterrestrial mining is undeniably an impactful technological system in regards to both scientific progress and societal norms. While the gathering of natural resources away from the planet is exciting from a distant view, the concept becomes much less simple upon closer inspection. In comparing applications of space mining to current practices on earth, applying the STS concept of the technological fix both casts doubt upon and invites discussion as to whether implementing space mining systems is the appropriate course of action to aid humanity's ever-growing resource demands. While no single mining system will be able to extract all of the resources discussed in this section, viewing each through the lens of a technological fix provides a nuanced look at the relation between current societal practices and future possibilities. The resources examined include helium-3 isotope, rare earth elements, and water. It is important to remember that classification as a technological fix is not necessarily a negative indictment of a technology, but rather an indication of alternate possibilities for the area in which the technology will be implemented (Newberry, 2005).

In analyzing the potential impacts of and conflicts created by space mining technology regarding international and societal relationships, it is obvious that they are indeed *political technologies* as described by Langdon Winner (1980). By using this STS framework, the second of the following two sections provides a view of both the potential conflicts space mining may cause, along with a view at how nations are currently dealing with these conflicts and how they may be dealt with in the future. Examined areas of impact include overall international diplomacy, resource networks, and national security. Again, the following section is not intended to pass judgement on or establish diplomatic plans for the implementation of space mining systems, but instead to apply the concept of these systems as political technology to investigate current and future impacts.

Technological Fix: A Comparative View of Space Mining Systems

Helium-3 Isotope

As explained in the previous concept background sections, Helium-3 is an isotope that is abundant on the moon's surface, and that has been theorized to be capable of providing nuclear power with great efficiency and without the generation of harmful radioactivity typically associated with nuclear power production (May, 2021; Gilbert, 2021). Although some such as University of Oxford theoretical physicist Frank Close have publicly stated that the presence of sufficient helium-3 on the moon along with the possibility of utilizing it for power production as stated previously is not possible and instead “moonshine” (2007), the following analysis is conducted under the assumption that Close is incorrect. Inevitably, the extraction of helium-3 from space would be with the goal of proliferating nuclear power as a worldwide energy source. However, it is not difficult to see this objective as a technological fix for constantly-increasing energy demand on the planet, especially given the range of alternatives available.

Even assuming that claims of “radiation-free” power generation are true, nuclear power still presents a number of negative side effects in areas where it is implemented. Nuclear reactors present both a worldwide and local safety risk where they are implemented in several ways. Firstly, presence of a reactor implicitly creates the risk of foul play, such as a terrorist attack meant to turn the reactor into a destructive object. Secondly, proliferation of nuclear power capability and knowledge creates the opportunity for nations without nuclear warfare capability to develop dangerous warheads. Finally, nuclear plants are also susceptible to natural events, becoming highly dangerous even without the threat of radioactivity in the event of an emergency (Johnson, 2018). Nuclear power plants also have negative impacts on the environment both during construction and when operational. These plants recycle large amounts of water for operation, usually drawn from natural sources such as lakes, rivers, or the ocean. This process has a number of negative impacts, including killing aquatic animals, upsetting ecosystems, and heating up natural water sources (NRDC, 2014). Finally, nuclear power currently comes at a high cost compared to other energy sources such as renewables and fossil fuels, and often lacks support from citizens and governments due to prior incidents such as those at Chernobyl, 3-Mile Island, and, more recently, Fukushima in Japan (Blum, 2022).

Ultimately, the negative aspects of nuclear power allow the mining of helium-3 on the moon to be categorized as a technological fix for the issue of worldwide energy usage and climate health. An obvious societal solution to the issue of energy usage exists in the form of campaigns to reduce overall energy usage by populations all over the world. It is not obvious however, that this solution will be sufficient to address an issue as large as energy shortages. While not necessarily society-based, renewable energies are also an undeniable technological solution for this issue. Although arguments can be made against this technological solution as well, it is a valid alternative to consider. According to the International Energy Agency, global renewable power capacity will increase by 50 percent by 2024 (Ghosh, 2022).

Rare Earth Elements

Rare earth elements are key components to a number of electronic technologies in modern society. In fact, the person currently reading this research is almost certainly doing so with the help of rare earth elements. Despite the widespread usage of these elements, they carry with them a number of ethical concerns. Firstly, rare earth elements are extremely difficult to extract on earth, and are scarce as a result of this obstacle despite high demand. Compounding this issue from an American perspective is that foreign countries such as China hold a near monopoly on the mining of rare earth elements (Lima et al., 2015). Arguably the most consequential impact of modern society's rare earth metal usage, however, is the extraction processes themselves. In recent years, a number of studies have been conducted at and around locations where rare earth elements are mined. In most cases, these studies have shown that both soils and natural water sources have been polluted by toxic acids and chemicals from the element extraction process (Lima et al., 2015). Additionally, this mining process has brought harm to foreign miners themselves, who have been subject to reported human rights abuses including exposure to unsafe substances, overworking, and negligible pay (Nayar, 2021).

Due to the large amounts of rare earth elements predicted to be present on celestial bodies, it could be argued that retrieval from outer space is a necessary goal, rather than a technological fix, due to the potential to eliminate the aforementioned harms to society and the environment from mining (May, 2021). While in the very long-term this viewpoint could indeed be correct, it does not hold up as well in a short-term perspective. The promise of vastly increasing rare earth element reserves could very easily prevent the global market from moving away from these materials, allowing mining to continue and present harm in many regions when done improperly. Additionally, even once rare earth metals are extracted, it will likely take some time for the quantity to be sufficient to make mining on earth unviable.

Mining for rare earth elements in outer space is apt for classification as a technological fix for rare earth metal issues on earth due to its potential negative impacts, along with the presence of alternative solutions. Indeed, projects have already been initiated to create materials that can be used in place of rare earths for applications such as electric vehicles and wind power generation, two major uses for these elements presently. Additionally, these projects incorporate materials that can be harvested more safely, and in more regions of the world (ARPA-E, 2011). Furthermore, a number of current initiatives exist for the recycling of rare earth metals from discarded electronics, reducing the need for further mining (Lima et al., 2015). Overall, the promise of mining for rare earth in outer space has the potential to stunt the growth of initiatives such as alternatives and recycling, giving the technological system merit as a technological fix, at least in the present.

Water

Presently, plans to mine water from outer space are with the objective of utilizing the substance in outer space, rather than returning it to earth. As mentioned previously, water is a useful molecule to be supplied for extraterrestrial missions and settlements without having to transport it from earth's surface, which decreases rocket mass and resulting launch cost (May, 2021). The more desirable quality of water mined and stored in outer space, however, is its ability to be split into hydrogen and oxygen, which are key components of rocket fuel. Storing rocket fuel in outer space means reducing the amount needed to be stored on a rocket exiting earth's atmosphere. Again, reducing the mass of a rocket at liftoff reduces the cost of a launch overall (Gilbert, 2021).

As with the previous two resources discussed, however, mining water in outer space to be used for rocket fuel does not come without drawbacks, despite its exciting potential. The major negative side effects of modern rocket propellants are in regards to pollution of the atmosphere, and in some cases, areas where spent rocket stages crash back to earth. More specifically, these pollution concerns are mainly from the fuels required in initial stages of rocket launches, when the greatest amount of thrust is required by a rocket. Although helium and oxygen propellant, as will be stored in outer space and used in later rocket stages, is a relatively clean propulsion source, this fuel is currently unable to provide sufficient thrust for the initial stage of launches (Pultarova, 2021). Due to helium and oxygen fuel's lack of propulsive ability, different and more environmentally hazardous fuels are used in initial stages of modern launches. In nations such as China and India, rockets use a fuel known as UDMH, which is environmentally toxic in its unburned state. Multiple studies have shown that initial rocket stages crashing back to earth with unburned UDMH cause severe environmental harm in the areas where they impact, whether land or sea (Ul'yanovskii et al., 2020; Byers & Byers, 2017). In launches from other nations, fuels such as kerosene and methane are used in early stages. While less harmful than UDMH, these fuels both pollute the atmosphere with large amounts of both carbon dioxide and soot when burned (Gammon, 2021). Additionally, leaking of these fuels prior to burning can substantially contribute to climate change by impacting the ozone layer (Pultarova, 2021).

As with mining for rare earth metals in outer space, mining for water in space is not necessarily hazardous in-and-of itself. Instead, the potential prevention of innovation of cleaner, more efficient rocket fuels allows storing of rocket propellant in outer space to be viewed as a technological fix for pollution from rocket launches. By allowing rockets to carry less propellant overall at liftoff by storing some in earth's orbit, it may become uneconomical to try and develop or implement new fuel types in the governmental or private sector. Overall, this prospect has potential to limit the research and usage of fuel types that have reduced negative impact on the surrounding environment.

Political Technology: Exploring International Impacts of Space Mining

International Diplomacy

As explained in previous sections of this document, space mining technology is accompanied by several dilemmas in international relations, of which two stand at the forefront. The first of these dilemmas is the Outer Space Treaty, a universally accepted United Nations treaty which contains language that can be interpreted as outright preventing retrieval of materials from outer space (1967). Given that this initial barrier can be cleared, a following dilemma exists in the form of deciding, for lack of a better phrase, "who gets what" from celestial bodies. This section will be written under the assumption that the Outer Space Treaty does not prohibit space mining, regardless of whether or not this is the case, due to the present attitudes of space-faring nations. Countries such as the United States, with the 2015 Space Act, and Luxembourg have already established legislation explicitly allowing companies to mine in outer space (Space Act, 2015; Skauge, 2020). Additionally, the Artemis Accords, currently ratified by 12 space-faring United States allies, permit space mining as within the bounds of the Outer Space Treaty (2020). While specific legislation is admittedly difficult to find for Russian and Chinese space programs, both nations have also begun development of plans and technology to mine in outer space (Cohen, 2021; Soldatkin, 2019).

Presently, international dilemma regarding space mining systems centers around the lack of a globally accepted agreement or treaty. As stated in the previous paragraph, nearly all space-faring nations have plans for implementing space mining systems, despite the fact that these nations have not universally collaborated on how resources will be claimed. Moreover, in many cases the legislation that exists within - and in some cases between - these respective nations leaves much to be desired. Within the United States, the contents of the Space Act of 2015 have met a number of critiques. These center around a lack of safety protocols regarding both environmental damage and interference from outside actors, along with the absence of a concrete licensing system for embarking on and conducting missions by private companies. Many of these same criticisms have also been levelled against the Artemis Accords (Sutherland, 2021). Overall, most present-day international regulations regarding space activity, and subsequently space mining, are regarded as "soft-law." Soft-law consists of "non-binding principles, norms, standards or other statements of expected behavior in the form of recommendations, charters, terms of reference, guidelines, [and] codes of conduct …," and is therefore unenforceable (Skauge, 2020). The Outer Space Treaty is an exception to this, but has been essentially disregarded in relation to space mining systems. A consequence of the unenforceability of soft-law governing space mining is the potential for international conflict (Skauge, 2020). In short, there are no firm and agreed upon guidelines for how to establish and operate space mining systems, opening the door for disputes and hostilities when these technological systems are put into practice.

In order to ensure prevention of international disagreement and potential conflict resulting from space mining systems, a universal agreement such as the Outer Space Treaty will need to be established. From a broad view, this agreement will almost certainly require establishment of a firm licensing body for mining missions with members from multiple involved nations, similar to committees within organizations such as the UN. In practice, the licensing process carried out by this committee can take two general forms, one capitalistic and one socialistic. A capitalistic form is simpler in concept, and would permit spacefaring nations to mine and keep whatever resources collected in outer space by that nation, given prior mining approval is given by the committee. A socialistic concept involves more steps, and could be similar to an international resource agreement already in place involving mining in international water: the UN Convention on the Law of the Sea. This agreement requires that nations mining the deep sea after committee approval create two mining sites, one for use solely by the applying nation, and one for the UN to mine on behalf of "developing nations" (Skauge, 2020). As applied to mining in outer space, an agreement such as this would involve distribution of space resources to nations that do not presently possess spacefaring capabilities. Regardless of the format, an international agreement and licensing process is a necessary step towards preventing space mining technology from creating conflict on the international stage.

<u>Resource Networks</u>

A large political aspect of space mining technologies is their potential to greatly disrupt international trade and resource networks. Currently, almost every nation in the world relies on other nations to at least some degree for imported natural resources. Conversely, these same nations rely on exporting resources as well in order to support their respective economies. In many cases, certain resources are either only found in certain areas of the world, or only widely collected in certain nations. If resources traditionally imported from other nations were suddenly available through collection in outer space, spacefaring nations would no longer be required to trade for them. For nations that export resources now available via space mining, demand for exports would decrease drastically. As a whole, trade networks and economies of many nations would be greatly impacted in either a positive or negative manner. As explained in the background section of this research, celestial bodies contain vast amounts of resources that are presently mined on earth. Among these celestial resources, rare earth elements and helium-3 isotope are likely to be the most impactful on present day resource collection networks.

In terms of rare earth element extraction and usage, nations such as China, Russia, Australia, and the United States are major international players. In 2019, China produced almost fifty percent of the global supply of rare earths both domestically and from mines located in Myanmar. The second largest producer of rare earths is currently the United States, followed by Australia via mines in Malaysia. Although current production is low, Russia possesses massive reserves of rare earths domestically, with plans to begin mining in the near future (‘Sourcing Rare Earths,’ 2022). The ability of nations such as China, Russia, and the United States to access virtually endless reserves of rare earths in outer space without trading with other nations will obviously shake up the current rare earth international distribution structure, along with impacting involved nations. Countries such as Australia, Malaysia, and Myanmar will likely feel the most negative immediate impacts, as they will lose the economic benefits of exporting rare earths to nations with space mining capability, and do not currently possess developed space programs (‘Sourcing Rare Earths,’ 2022). For China, Russia, and the United States, impacts will be more positive overall. As with other rare earth exporting nations, the loss of several trade partners will be economically detrimental. However, the ability to be self-sufficient in rare earth element extraction and usage, along with the potential to export to nations without space mining capabilities will certainly outweigh all economic drawbacks.

Impacts of mining for helium-3 isotope in outer space are nearly identical to those of mining for rare earth elements. As explained in the background section of this research, helium-3 is a theoretical fuel for nuclear power and, if utilized, would take the place of uranium in energy production. As with rare earth metals, collection of helium-3 from outer space by spacefaring nations would most negatively impact uranium exporters without developed space programs. Currently, a majority of the world's uranium is exported from nations including Canada, Namibia, Kazakhstan, Niger, and Australia, none of which possess space programs capable of conducting mining in the near future (World Nuclear Association, 2021).

National Security

A final major impact of space mining technology on the international stage is on the development and implementation of national security measures in outer space. Inevitably, the placement of highly valuable and expensive national technology in a vulnerable position invites interference from hostile actors seeking to destroy or disrupt said technology. Space mining systems fit this situation well, as a critical technology that would be left essentially unprotected in outer space without an accompanying security system. Many nations are already in the process of developing and improving weapons that can be launched from the earth's surface and destroy targets in outer space. Although currently these weapons are focused primarily on satellites, it is not a stretch to imagine that mining systems on celestial bodies could be targeted as well once they are put in place. Presently, spacefaring nations including China, India, Russia, and the

United States all possess anti-satellite weapons (ASATs) capable of being deployed from the earth’s surface and destroying or disrupting a target in orbit (Blatt, 2020). As recently as last year, in fact, the Russian military tested an ASAT on a defunct satellite in orbit, completely destroying it and sending a cloud of dangerous debris into orbit around the earth (Hennigan & Kluger, 2021). In the past, both China and the United States have conducted similar tests (Blatt, 2020).

Because of the threat of attacks from other nations, the existence of space mining systems prompts the continuing development of national security systems and technology to be implemented with regard to outer space. As a whole, defense mechanisms for satellites and space technology are presently very limited, due to high costs and difficulty maneuvering in an orbital or stationary environment. Due to this limitation, outer space is often considered “offense-dominant,” and protection of space systems is largely focused around deterrents and the capability for retaliations against hostile actors (Blatt, 2020). As a result, increasing security of a nation’s space systems, such as mining technology, corresponds to increasing offensive capabilities against space systems belonging to other nations. These offensive capabilities include aforementioned anti-satellite missiles, along with less destructive options meant to disable space systems without destroying them, such as electronic jammers or powerful lasers (Blatt, 2020). Today, nearly all spacefaring nations have governmental agencies dedicated to protection of outer space assets. In 2019, United States president Donald Trump announced the creation of a new military branch known as the “Space Force” intended to “protect U.S. and allied interests in space” (United States Space Force, n.d.). In 2015, Russia organized the Russian Aerospace Forces service, while China formed the People's Liberation Army Strategic Support Force Space Systems Department, both with goals similar to the United States’ Space

Force (‘Space Force,’ 2017). With the implementation of space mining technology, organizations such as these will only continue to grow in size and importance.

Research Reflections

Overall, this research is somewhat limited in scope due to the large number of societal and technological implications resulting from space mining technologies. The previous section gives what could be considered a broad view at each discussed topic, and certainly is not all encompassing in terms of topics to be considered. In truth, each of the six subsections in the previous section could be expanded into full research topics themselves without a great amount of effort. Given that this research was fully developed, conducted, and transcribed by a single author, however, much information had to be condensed in order to construct a coherent and comprehensive research paper. A subsequent limitation of this research is the relative infancy of space mining technology. When discussing applications and impacts of space mining systems, most information is purely speculative, as no one has actually begun mining in space prior to the conduction of this research.

In the future, each of the six topics from the previous section could be looked into and developed further. As stated previously, all six have the potential to be expanded into their own full research topics. Additionally, further political impacts and varieties of resource collection certainly exist within the concept of space mining technology. Further research could be conducted on any subsequent impacts and resource types as they are identified. In this research, the most salient political effects and likely materials to be collected in outer space were analyzed. However, there are undeniably further aspects of each of this research’s two topics. Finally, as space mining systems are actually implemented in the future, this research could be revisited as an aid to examine actual, rather than prospective, results of space mining technology.

Closing Remarks

As a whole, space mining systems are apt for analysis using the STS framework of the *technological fix*. Analyzing the current mining objectives of retrieving rare earth elements, helium-3 isotope, and water as technology-based solutions for issues facing society sheds light on both the ethicality and practicality of a technological system that will likely be a large part of humanities' future. Similarly, viewing space mining systems as *political technologies* reveals a number of important international impacts that space mining technology currently possesses, and will likely have on society in the future. Specifically, salient impacts include disruptions and alterations to the international and societal categories of diplomacy and relations, resource and trade networks, and national security development. Overall, this research should reveal space mining systems as a technology with potential for considerable societal disruptions, for better or for worse. As a result of this potential, it is important for both involved engineers and society as a whole to have a general understanding of the applications and impacts of extraterrestrial mining technology while it is still in development, and malleable in final form.

References

Advanced Research Projects Agency–Energy [ARPA-E] (2011). *Rare Earth Alternatives in Critical Technologies*. https://arpa-e.energy.gov/technologies/programs/react#:~:text=The%20projects%20that%20comprise%20ARPA,EV)%20motors%20and%20wind%20generators.

Arms Control Association. (n.d.). The Outer Space Treaty at a Glance. Arms Control Association. Retrieved September 29, 2021, from https://www.armscontrol.org/factsheets/outerspace

Artemis Accords, October 13, 2020. https://www.nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf

Blatt, T. (2020). Anti-Satellite Weapons and the Emerging Space Arms Race. *Harvard International Review, 41*(3), 29–34.

Blum, A. (2022, January 17). The Promise of Nuclear. *TIME Magazine*, 199(1/2), 44 - 50.

Byers, M., & Byers, C. (2017, November 1). Toxic splash: Russian rocket stages dropped in Arctic waters raise health, environmental and legal concerns. *Polar Record*, 53(6), 580 - 591.

Captain, S. (2019, May 9). *Jeff Bezos wants to save Earth by moving industry to space*. Fast Company. Retrieved September 29, 2021, from https://www.fastcompany.com/90347364/jeff-bezos-wants-to-save-earth-by-moving-industry-to-space.

Close, F. (2007). Fears over factoids. *Physics World, 20*(8), 16. https://iopscience.iop.org/article/10.1088/2058-7058/20/8/24

Cohen, A. (2021, October 26). *China's space mining industry is prepping for launch – but what about the US?* Forbes. Retrieved March 16, 2022, from https://www.forbes.com/sites/arielcohen/2021/10/26/chinas-space-mining-industry-is-prepping-for-launch--but-what-about-the-us/?sh=64a304ae2ae0

Etzioni, A. (1968). Shortcuts to Social Change?. *Public Interest, 12*, 40–51.

Gammon, K. (2021, July 19). *How the billionaire space race could be one giant leap for pollution*. The Guardian. Retrieved March 10, 2022, from https://www.theguardian.com/science/2021/jul/19/billionaires-space-tourism-environment-emissions

Ghosh, P. (2022, January 5). *Nuclear power 101*. NRDC. Retrieved February 20, 2022, from https://www.nrdc.org/stories/nuclear-power-101

Gilbert, A. (2021, April 26). Mining in Space is Coming. Milken Institute Review. Retrieved September 29, 2021, from https://www.milkenreview.org/articles/mining-in-space-is-coming.

HENNIGAN, W. J., KLUGER, J., Barry, E., Bennett, B., Cachero, P., Carlisle, M., Law, T., Mansoor, S., Nugent, C., Perrigo, B., & Waxman, O. B. (2021). Russia's anti satellite test threatens ISS. *TIME Magazine*, *198*(21/22), 22–23.

Johnson, N. (2018, April 11). *Nukes of Hazard*. Grist. Retrieved February 20, 2022, from https://grist.org/technology/nuclear-is-scary-lets-face-those-fears/

Lima, I. B., Leal Filho, W., & Knovel, A., M. &. M. (2016). *Rare Earths Industry: Technological, Economic, and Environmental Implications.* Amsterdam, Netherlands: Elsevier.

May, A. (2021). The Space Business: From Hotels in Orbit to Mining the Moon - How Private Enterprise Is Transforming Space. London, UNITED KINGDOM: Icon Books Ltd.

Natural Resources Defense Council [NRDC] (2014, April). *Power Plant Cooling and Associated Impacts: The Need to Modernize U.S. Power Plants and Protect Our Water Resources and Aquatic Ecosystems*. https://www.nrdc.org/sites/default/files/power-plant-cooling-IB.pdf

Nayar, J. (2021, August 12). *Not so "green" technology: The complicated legacy of rare earth mining*. Harvard International Review. Retrieved February 22, 2022, from https://hir.harvard.edu/not-so-green-technology-the-complicated-legacy-of-rare-earth-mining/

Newberry, B. (2005). Technological Fix. In C. Mitcham (Ed.) *Encyclopedia of Science, Technology and Ethics*. (Volume 4., pp. 1901-1903). New York, New York. Macmillan Reference USA.

Pultarova, T. (2021, October 28). *The environmental impact of rocket launches: The 'dirty' and the 'green'*. Space.com. Retrieved February 22, 2022, from https://www.space.com/rocket-launches-environmental-impact

Skauge, T. (2020). Space Mining & Exploration: Facing a Pivotal Moment. *Journal of Corporation Law*, *45*(3), 815–832.

Soldatkin, V. (2019, March 6). *Russia wants to join Luxembourg in Space Mining*. Reuters. Retrieved March 15, 2022, from https://www.reuters.com/article/us-luxembourg-russia-space/russia-wants-to-join-luxembourg-in-space-mining-idUSKCN1QN1OQ

Sourcing Rare Earths. (2022). *Earth Island Journal*, *36*(4), 8–9.

Space force. (2017, October 3). In *Wikipedia*. https://en.wikipedia.org/wiki/Space_force

Sutherland, H. (2021). The Stakes Are out of This World: How to Fix the Space Act of 2015. *Vermont Journal of Environmental Law*, *22*(1), 100–129.

Text - H.R.2262 - 114th Congress (2015-2016): U.S. Commercial Space Launch Competitiveness Act. (2015, November 25). https://www.congress.gov/bill/114th-congress/house-bill/2262/text

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), Jan. 27, 1967.

Ul'yanovskii, N., Lakhmanov, D. E., Pikovskoi, I. I., Falev, D. I., Popov, M. S., Kozhevnikov, A. Yu., & Kosyakov, D. S. (2020, July 15). Migration and transformation of 1,1-dimethylhydrazine in peat bog soil of rocket stage fall site in Russian North. *Science of the Total Environment*, 726

United States Space Force. (n.d.). FAQs. https://www.spaceforce.mil/About-Us/FAQs/

Weinberg, A. (1966). Can Technology Replace Social Engineering? *Bulletin of the Atomic Scientists, 12*(10), 4-8.

Winner, L. (1980). Do Artifacts Have Politics? *Daedalus*, *109*(1,), 121–136.

World Nuclear Association. (2021). Uranium Mining Overview. https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/uranium-mining-overview.aspx