2 The Importance of Natural Resources from Space and Key Challenges

Earth is a 6 sextillion-ton globe that contains a wealth of resources. These natural resources can be extracted from the atmosphere, the oceans and the ground. If these resources are used wisely and in a sustainable fashion they should be able to be recycled and used over and over again. However, as the global population has increased from 800 million in 1800 to 1.8 billion in 1900 to 6.3 billion in 2000 and to well over 7 billion today, the demand for fossil fuels for transportation and energy needs has expanded greatly, as well as the need for various metals and other rare earth materials. Modern civilization with its complex infrastructure, burgeoning population, and surging urban complexes that will within three decades contain 70 % of all humanity, is in need of significant re-engineering to adjust to twenty-first century realities. In a world with perhaps a 100 megacities of more than 10 million people each, significant elements of climate change, major environmental shifts, and natural resource needs, the world as we know it today will have to significantly change, or it will no longer be sustainable.[1]

Some of the most significant changes that will have occurred by the time of the twenty-second century are the following:

- Human population stabilization. The exponential growth of human population that has characterized the eighteenth, nineteenth, and twentieth centuries will likely give way to a zero population growth profile in the twenty-first century at a level between 10 and 12 billion people. Even at this level demands on natural resources, climate change issues, and food and energy needs will be challenging. Continued growth within the energy, food and natural resource limits is not sustainable. This new world that is 70 % or more urban will

[1] Joseph N. Pelton and Peter Marshall, *Megacrunch: Ten Survival Strategies for 21st Century Challenges* (2010) PMA Associates, London, United Kingdom.

R.S. Jakhu et al., *Space Mining and Its Regulation*,
Springer Praxis Books, DOI 10.1007/978-3-319-39246-2_2

be far more vulnerable to the loss of critical infrastructure.[2]

- Shift to sustainable sources of energy. Twenty-first century energy systems will be weaned off of fossil fuels, and there will be a gradual shift to solar, wind, geothermal, hydroelectric, tidal, and nuclear fusion-based energy systems. In making this transition, efforts to decentralize power supplies can add to sustainability and survivability of urban communities.
- Climate change stabilization. The efforts to stabilize Earth's climate and slow down natural and human-fueled climatic shifts will increase. It may be recognized in coming decades that space-based solutions—such as a space-based shield at Lagrange Point One or space-based heat pipes or other mega-engineering projects may be needed to provide ultimate answers. This is not only an issue of human avoidance of mass extinction but also an issue of the preservation of a wide range of animal and plant life.
- New patterns and forms of urbanization. The last two centuries has brought about a vast shift in global patterns of urbanization. The shift from less than 5 % urban to over 70 % urban will have occurred in less than 200 years. This change has been driven first and foremost by jobs and employment. In an age of optical and electronic computer and telecommunications networks, increasing super automation and robotics, and a service economy, the current patterns of super-urbanization are no longer necessary and indeed are dangerous in terms of over concentration of populations. Increasingly, there will be shifts in patterns of urbanizations. New "meta cities" that are geared to twenty-first century telecommunications, networking, energy and transportation systems will serve to relieve pressures on megacities of 10 million or more people. Telework can help ease the problems of super urbanization and over concentration of population.[3]
- Space systems for planetary defense. Over the next few decades planetary defenses will shift from threat detection to threat protection. Space systems can be developed to alleviate threats from solar storms, a weakening geomagnetosphere, potentially hazardous asteroids and comets, and even threats from runaway orbital debris. Ultimately space programs and systems will be recognized not as luxuries but rather as essential capabilities to preserve the human race against mass extinction. Capabilities developed to support space mining will contribute vital technologies to achieve effective planetary defense as well as provide vital resources for the future.
- Exhaustion of planetary natural resources and a new extra-terrestrial based economy. Secretary of State John Hay once famously said: "The Mediterranean is the ocean of the past, the Atlantic is the ocean of the present, and the Pacific is the ocean of the

[2] Indu Singh and Joseph N. Pelton, *The Safe City: Living Free in a Dangerous World* (2013), The Emerald Planet, Washington, D. C., pp. 193-198.

[3] *Ibid*., pp. 215-233.

future."[4] And over time the global economy has expanded to make this prediction a reality. Soon the economies of China, India, Indonesia, and Japan plus the smaller countries of Singapore, Taiwan, Republic of Korea, Thailand, etc., will outstrip those of the United States and Europe. As these developing economies grow more prosperous and demand for natural resources continue to grow the availability of natural resources will become an increasing problem. In looking to the future it might be well to consider the predictions of Ray Kurzweil and his forecast of the coming "Singularity."[5] Or perhaps to consider the vision of Peter Diamandis in forecasting a future that is increasingly based on an extra-terrestrial and space-based economy. The value of platinum-rich asteroids has been estimated at levels ranging from $200 billion up to even a trillion dollars. Of course the future of our energy needs rest with the Sun. With ever growing space-based capabilities and the cost of going into space ever decreasing, the reality of a space-based economy becomes more realistic every year.[6]

[4] John Hay quote on the Pacific as the ocean of the future https://books.google.com/books?id=5P9bgGxfYKUC&pg=PA118&lpg=PA118&dq=John+Hay+quote+on+Pacific+ocean&source=bl&ots=8Tb4vBEDMm&sig=k6wOGDKzmnb3DHqVonBrhSE9AVA&hl=en&sa=X&ved=0CDMQ6AEwA2oVChMI35rYq8q_xwIVU4MNCh1YgAjL#v=onepage&q=John%20Hay%20quote%20on%20Pacific%20ocean&f=false

[5] Ray Kurzweil, How to Create a Mind (2012), Penguin Group, London, U.K.

[6] Peter Diamandis, *Abundance: The Future is Better than You Think*, (2012) Free Press, New York.

Gauging the Future

The future is most often viewed through a rearview window. And for millions of years of biological evolution the past was indeed often prologue to the future. With the advent of technology, computer and communications networks, artificial intelligence, robotics, and the ability to go into space, the rate of change in human civilization has increased exponentially. In Fig. 2.1 the "Super Month" graphic compresses the time since the age of the Southern Ape Man into a 30-day period where every second represents 2 years. In Super Month time the age of farming and permanent settlements represents the last hour and a half of the last day of the month, the Renaissance is the last 4 min, and the Industrial Age is 2 min until midnight. The age of computers, cell phones, television, bio-engineering, megacities, space launches and spandex—all the elements of modern life we take for granted—represent only the last 20 s of "Super Month" time.

This graphic serves to demonstrate that judging future societal needs on past experience is a seriously flawed concept. The future needs of human civilization in terms of energy, housing, transportation, water, natural resources, jobs and employment, and security are dramatically different that they were ever before. As an illustrative example, it has been artfully noted that it would be far easier for Moses to come and live in the times of Napoleon and Thomas Jefferson than for someone living in the eighteenth century to come forward and live in today's world of advanced technology.

When Peter Diamandis talks of "abundance" and Ray Kurzweil talks of

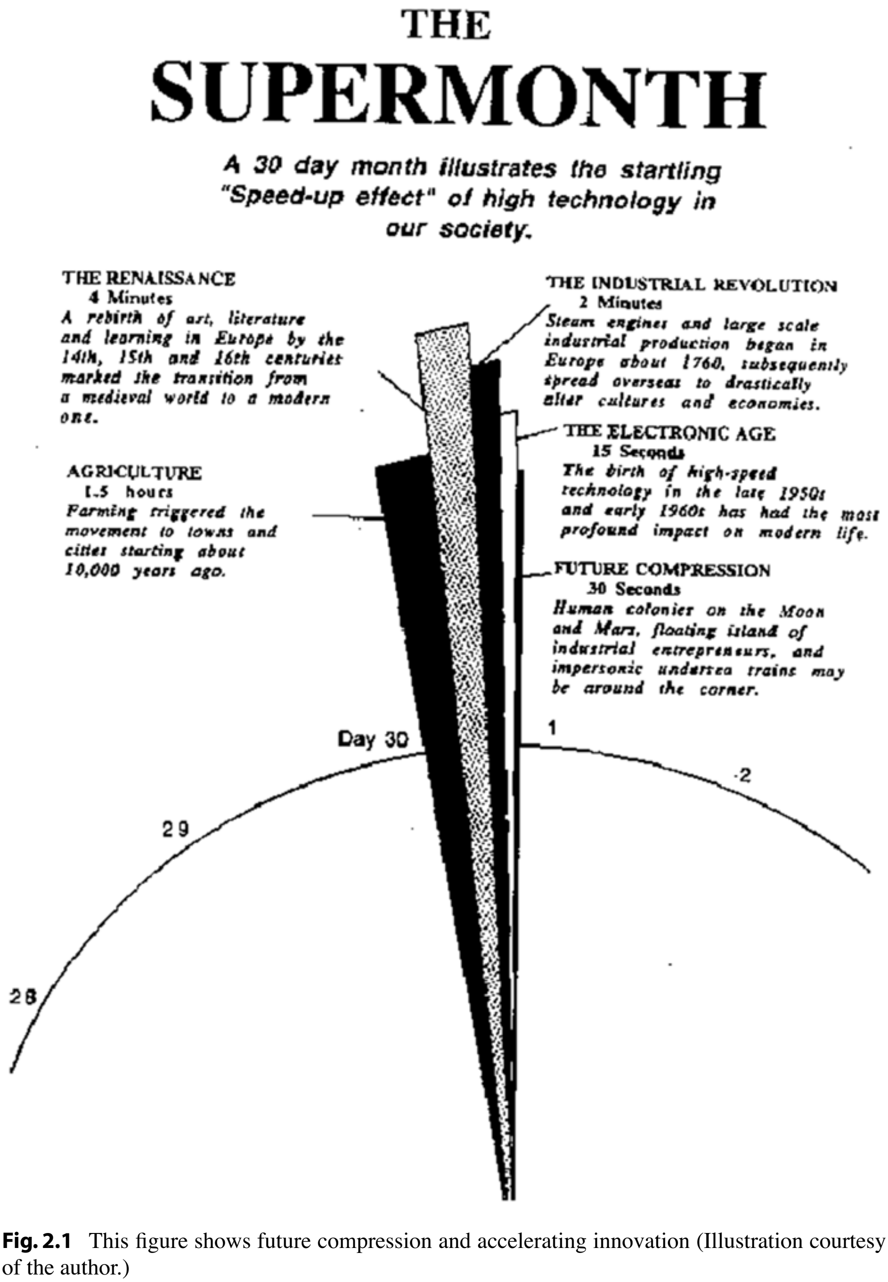

Fig. 2.1 This figure shows future compression and accelerating innovation (Illustration courtesy of the author.)

"the singularity," they are suggesting a world that is far different than we ever experienced before. They envision a world in which we cohabitate with robots that are as smart as humans and possess sophisticated "thinking" skills, space probes that can be used to bring us new resources and clean energy from

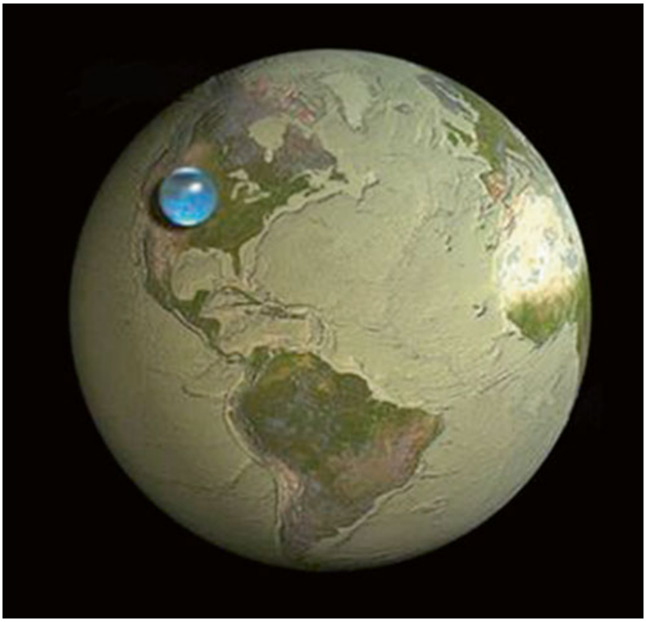

Fig. 2.2 The volume of Earth's accessible water in comparison to the volume of the world (Graphic courtesy of the Sierra Club.)

space and also protect our critical infrastructure from cosmic hazards.

Coping with the Scale and Complexity Problem

The land area of the entire world is 148.94 million sq. km (or 57.506 million sq. miles), and its water area is 361.132 million sq. km (or 139.434 million sq. miles). About half of that land area is truly viable for year- round habitation when one eliminates most parts of Antarctica, the Arctic north, Siberia, the most dangerous mountain ranges and the most arid desert regions. Rising sea levels will further decrease available land areas. When one divides about 75 million sq. km by 10 billion people (or about 133 people people/sq. km) it becomes clear that rising global population and shrinking land areas and exhaustion of many types of natural resources—especially potable water—will be a growing problem.[7] Figure 2.2 shows the volume of water in the world in comparison to the total volume of Earth. This graphic helps us to realize just how small the amount of potable water that is truly accessible today in comparison to a rising global population actually is.

Figure 2.2 underscores the issue of just how difficult it will be to continue to provide key resources especially to major urban centers as global population continues to grow. And this is not

[7] A profile of the world https://www.google.com/search?sourceid=navclient&ie=UTF-8&rlz=1T4VSND_enUS583US595&q=What+is+the+Land+area+for+the+world%3f (accessed August 24, 2015).

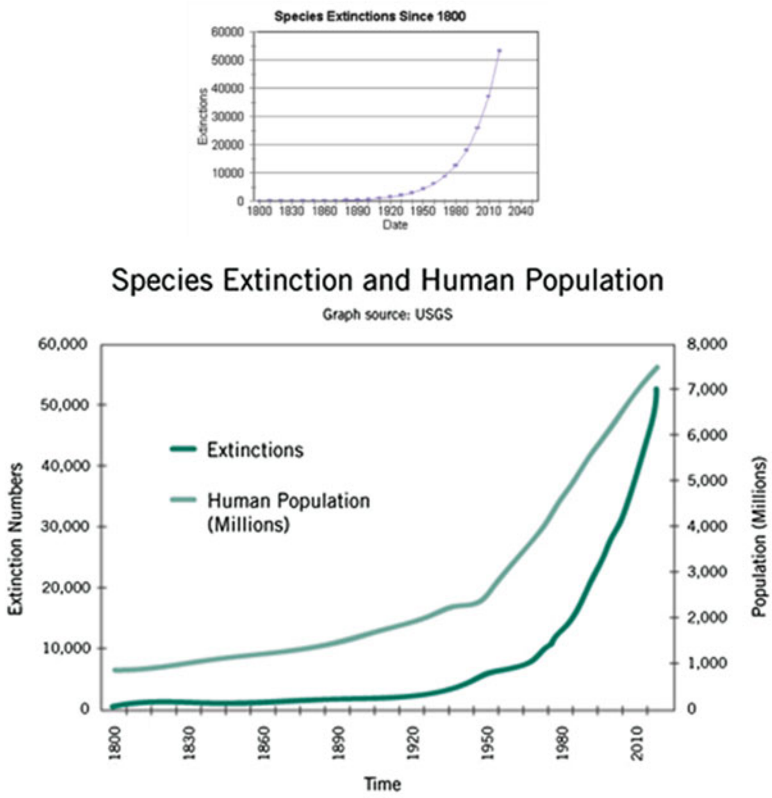

Fig. 2.3 Rise of extinction levels of species vs. human population growth (Graphic courtesy of the U. S. Geological Survey.)

just a question of sustaining human needs for water and natural resources. It is also a matter of sustaining endangered species of flora and fauna. The United Nations had done an analysis that shows the loss of species since 1800 and projections for the future show a very disturbing trend.[8]

[8] Gail Tverberg, "A Look at the Latest UN Predictions on Natural Resource Consumption, http://oilprice.com/Energy/Energy-General/A-Look-At-The-Latest-United-Nations-Predictions-On-Natural-Resource-Consumption.html.

The graphs in Fig. 2.3 that come from the U. S. Geological Survey seem to show a relationship between the rapid growth of the global human population in recent times and the increasing rate of extinction on species.

The future availability of petroleum products and water is most often mentioned in studies of future resource scarcity, but broader studies have shown that the world by the mid twenty-first century will have many shortages. The following results from a detailed Global Nonrenewal Natural Resources (NNR) study came up with the following

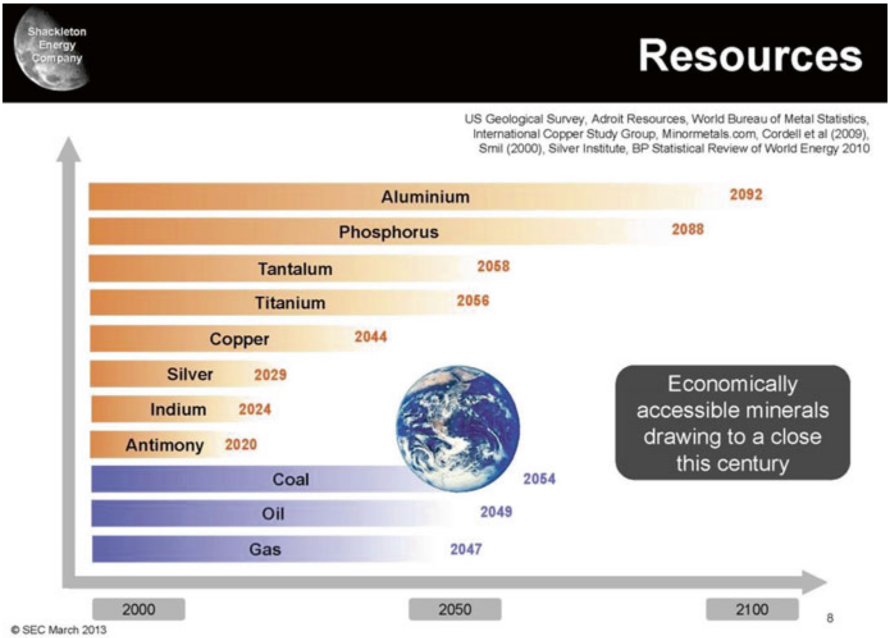

Fig. 2.4 Projected shortages of economically accessible minerals (Graphic courtesy of Shackleton Energy Company.)

results, as shown in Fig. 2.1.[9] Although these results might vary somewhat from year to year based on economic downturns or upturns, the overall trend toward increasing shortages is clear. The upward mobility of the populations in China, India, Indonesia, and other newly industrialized companies suggest that up to three times more consumer demand for products and energy will be present by the middle of the twenty-first century. Only recycling and new energy sources can meet the great bulk of this burgeoning demand. Meeting the demand for natural resources has been identified as a problem by many that have researched this problem. The projections of shortages in the future are presented in Fig. 2.4 and in even greater detail in Fig. 2.5 are certainly of concern. As Chris Clugston's detailed analysis of this subject has concluded: "Global Non Renewable Natural Resource (NNR) scarcity will intensify going forward, as global economic activity levels, economic growth rates, and corresponding NNR demand return to their pre-recession levels; and global NNR supply levels continue to approach and reach their geological limits."

Yet the prospect of space mining can provide new options. A modest near-Earth asteroid rich in platinum, approximately spherical in shape and 30 m in diameter would constitute a volume of 4500 cu. m and represent a mass of

[9] Chris Clugston, "Increasing Global Nonrenewable Natural Resource Scarcity—An Analysis http://www.resilience.org/stories/2010-04-06/increasing-global-nonrenewable-natural-resource-scarcity%E2%80%94-analysis.

Pre-recession (2000-2008) Global NNR Scarcity Summary

Extremely Scarce (6)	Very Scarce (21)	Moderately Scarce (22)	Marginally Scarce (1)	Not Scarce (7)
Bromine	Aluminum	Antimony	PGM	Arsenic
Gold	Bauxite	Beryllium		Barite
Mercury	Cadmium	Bismuth		Boron
Tantalum	Cement	Coal		Diamond
Tellurium	Chromium	Cobalt		Garnet
Thallium	Copper	Gallium		Lithium
	Fluorspar	Germanium		Niobium
	Magnesium Compounds	Graphite		
	Molybdenum	Gypsum		
	Natural Gas	Indium		
	Nickel	Iron Ore		
	Nitrogen (Ammonia)	Lead		
	Oil	Lime		
	Phosphate Rock	Manganese		
	Potash	Salt		
	REM	Silicon		
	Rhenium	Silver		
	Selenium	Soda Ash		
	Strontium	Tin		
	Sulfur	Vanadium		
	Tungsten	Zinc		
		Zirconium		

Fig. 2.5 An analysis of non-renewable natural resources reaching their geographic limits (Note: This chart is derived from information included in an article by Chris Clugston entitled "Increasing Global Nonrenewable Natural Resources—An Analysis," *The Oil Drum,* April 6, 2010.)

perhaps 5000 metric tons. If one assumed that this asteroid was 50 % platinum, then its value at current world market prices would be on the order of \$90 billion. Even if the asteroid recovery mission and refinement costs ran to \$5 billion and even if some of the proceeds were to go into some sort of global commons development or ecological fund, just a single such mission would produce many billions of dollars in profits. This may represent an extreme example, but there are over a million PHAs that are on the order of 30 m. The key in the early days of space mining would be to identify high-value targets.

A 50-m PHA would be over 4.6 times more massive in volume and content and would be incredibly valuable if it contained precious metals or rare earth materials such as iridium, rhodium, ruthenium, palladium, or osmium. In contrast, the economics would be much more difficult in the case of PHAs with less valuable natural resource contents. An asteroid with 70 % nickel and molybdenum content and 50 m in diameter would have something like a market value of only about \$200 million based on current market prices of \$13,000 a metric ton for molybdenum and \$10,000 a metric ton for nickel. This much lower valuation would call for space mining transport equipment of the longer term future that could be used over and over again. It would also likely mean systems that ran off of solar and electric propulsion systems.

It is important to note that space mining activities can be cost effective for recovering at least rare metals, but it is also noteworthy that even hydrogen, oxygen or water or other volatiles in space can also be valuable. The

Planetary Resources website states: "In orbit, spacecraft propellant is a multi-billion dollar industry with each pound of fuel worth more than an equivalent pound of gold on Earth. Certain asteroids are loaded with hydrogen and oxygen, the components of rocket fuel. These asteroids can provide a fuel source that is 100 times closer energetically to Earth orbit, and thus far less expensive, than the Apollo-Era "bring-everything-with-you" propellant used today."[10]

But the space mining industry can also aid in producing and perfecting new technologies that could assist with other types of space missions, or produce innovations that can find useful implementation right here on Earth. Space mining activities will be seeking to develop new and more cost effective robotics missions, advanced navigation and precision maneuvering in space, improved space situational systems, lower cost satellite manufacturing techniques, and improved power systems, including higher efficiency photovoltaic cells and quantum dot technology.

Of course the most important contribution could well be more cost effective space transportation systems such as solar-powered electric propulsion systems. If one could develop transport systems that are largely multi-use that can be used over and over again, they could also be employed to boost cost effective solar power satellites into orbit.

Likewise if space mining enterprises can develop low cost satellites that could produce at lower cost and in high volume via 3-D printing, such as Planetary Resources is now developing, this could be quite significant. Such techniques could also find application in communications, precision satellite navigation, and remote sensing constellations and on other space missions. Clearly low cost remote surveying and reconnaissance satellites are currently the top priority for space mining ventures, and Fig. 2.6 shows the prototype small satellite that Planetary Resources Inc. together with 3D Systems is currently developing. This Arkyd-300[3] satellite bus configuration as pictured below with its efficient torus shape holds the propellant and provides the structure for the satellite. The fact that the satellite can be "manufactured" via 3D printing, of course, greatly reduces its production cost. One of the characteristics of the new space mining companies is that they have typically recruited partners that can help them develop these new types of technology. They have also been skillful in winning contracts from NASA for research and development work.[11]

Coping with Legal, Regulatory and Standards Problems

The current state of the space mining incipient industry is that they have been far more adept at identifying the scientific, engineering and technological challenges to be faced and pursuing systems solutions than they have been at

[10] Planetary Resources overview, http://www.planetaryresources.com/company/overview/#why-asteroids (accessed August 24, 2015).

[11] 3D Systems and Planetary Resources Announce Investment and Collaboration, June 26, 2013. http://www.planetaryresources.com/2013/06/3d-systems-and-planetary-resources-announce-investment-and-collaboration/.

Fig. 2.6 (*Left to right*) Peter Diamandis, Chris Lewicki, and Steve Jurvetson of Planetary Resources unveiling the Planetary Resources 3D-printed satellite in February 2014 (Image courtesy of Planetary Resources.)

addressing what might be called the legal, regulatory, and standards problems that this new type of enterprise entails.

The only "established" international law that has widespread acceptance is the Outer Space Treaty.[12] The so-called Moon Treaty has only a few signatories and has not been signed by many space powers. Other provisions such as the Liability Convention is also relevant as well as various efforts to define provisions regarding the use of nuclear systems in space. The most relevant parts of the Outer Space Treaty are Articles 1 and 2 that state:

> ***Article I***
> *The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.*
>
> *Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without*

[12] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

> *discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.*
>
> *There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation.*
>
> ***Article II***
> *Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.*

Despite these provisions there are at least three private entities seeking to engage in space mining activities. One of the key questions discussed in the book is exactly what the definition of a celestial body is and whether a small asteroid of which there are millions constitutes a celestial body. Clearly such asteroid mining of small and potentially hazardous bodies would seem much more permissible under the Outer Space Treaty than efforts to establish national or private colonies on the Moon or to undertake mining operations on the Moon.

There are currently a number of efforts underway to seek to clarify the future prospects for space mining activities—whether they might be governmental or private ventures—and to address the future legal and regulatory status of such undertakings. This effort includes the McGill University Air and Space Law Institute "Global Space Governance Study" that devotes a chapter to this topic. From a practical rather than a legal viewpoint it would seem that the projects by Planetary Resources and Deep Space Industries seem to have less of a legal, regulatory or standards challenge to their proposed efforts than Shackleton Energy, which is focused on mining on the Moon.

Conclusions

The website of Planetary Resources contains the grand statement that inhabitants of Earth are currently limited to the finite resources found on our planet, but that we do not have to be limited to this fate over the longer term future. There indeed may be a need to create structures in space to defend our planet against extreme solar storms and new types of space infrastructure to beam new forms of clean energy down to the ground. The future is clearly not what it used to be. New space industries could indeed change our future—perhaps for the better or perhaps for worse. The "future compression" innovations that are bringing future realities to the fore at an ever more rapid pace in "Super Month Time" are ever more apparent each day. These changes will require institutional and legal responses in a more proactive manner. The ever growing innovations that include a wide range of new space initiatives will continue to bring the future into our lives with an urgent necessity.

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