IAN CHRISTENSEN, IAN LANGE, GEORGE SOWERS,
ANGEL ABBUD-MADRID, AND MORGAN D. BAZILIAN

# NEW POLICIES NEEDED TO **ADVANCE SPACE MINING**

Space has long captured the human imagination—as a source of wonder, a place of discovery, a realm for aspirations. But increasingly, space is viewed as a frontier of economic opportunity as scientists, technologists, and entrepreneurs invest their ingenuity and wealth to bring the vastness of space within human grasp.

This economic development hinges on an ability to utilize what we term "space resources." The resources in just the inner solar system are nearly infinite compared with those on Earth. For example, one large metallic asteroid such as 16 Psyche is thought to contain enough metals to last humans for millions of years at current consumption rates. And society has barely scratched the surface in harnessing the energy of the sun. Accessing space resources is increasingly important as the world confronts the finite nature of resources and the increasing environmental and social costs to develop them.

Moreover, if humans are ever to pursue large-scale permanent developments beyond low-Earth orbit—past the population of satellites and space stations—it will be necessary, because of energy and economic costs alone, to obtain the needed resources in space rather than transport them from Earth. Accordingly, most business concepts based on using space resources focus on in-space applications, as opposed to returning resources to Earth.

The current US administration is beginning to recognize the importance of space resources. Notably, President Trump on December 11, 2017, issued the "Presidential Memorandum on Reinvigorating

America's Human Space Exploration Program," commonly referred to as Space Policy Directive 1, instructing the National Aeronautics and Space Administration (NASA) to return humans to the Moon for "exploration and utilization." Vice President Pence backed this up at the 34th Space Symposium, held in April 2018 in Colorado Springs, Colorado, declaring that "American astronauts will return to the Moon to explore its surface and learn how to harness its resources to launch expeditions to Mars."

To achieve this anticipated development, progress must be made in science, technology, business, policy, and law. At the international level, space law (and policy) begins with the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which was adopted in 1967 and signed by the United States and 104 other countries. Generally known as the Outer Space Treaty, it states that the Moon and celestial bodies are not subject to national appropriation by claims of sovereignty. Yet it also states that those same celestial bodies are free for exploration and use by all nations. A perceived tension exists between these statements where space mining is concerned, as such activity requires some possession right (not necessarily permanent) to regions in space.

The Outer Space Treaty also requires that nations establish "authorization and supervision" processes to oversee the activities of their nongovernmental organizations (including private commercial companies) in space. The treaty and its associated national implementation have enabled a wide range of commercial activities that utilize the space domain, including remote sensing, communications, and rocket launch, and a number of government space agencies have conducted limited scientific activities involving utilization or sample return of space material. Yet it is the combination of commercial activity and use of space resources that creates perception of tension. Some groups have expressed concern over a perceived gap in the law that creates uncertainty, while others have expressed concern that use of space resources might be conducted to benefit only a few companies and spacefaring nations, and still others argue that the activity is illegal until a binding international regime is put into place to oversee it.

## Mining in Space

Until recently, space mining has been the purview of science fiction and movies. But now, companies have been formed with the explicit purpose of mining both the Moon and asteroids. Examples include Moon Express in the United States and iSpace in Japan and Europe. Even tiny Luxembourg is betting big. It has formed a Space Resources initiative focused on attracting "space companies from all over the world which see Luxembourg as the European hub in the exploration and use of space resources." Toward this goal, the country has already established what it calls a "unique legal, regulatory and business environment enabling private investors and companies to explore and use space resources."

Space resources are as varied as resources on Earth. They include solar power beamed from space, minerals, metals, gases, rare earth elements, helium 3 (as a fuel for nuclear fusion power generation), and materials for space manufacturing (the fabrication of goods in space). Yet ordinary water is the focus of most serious near-term development efforts. Water, when split into its constituents, hydrogen and oxygen, provides the most efficient chemical rocket propellants known. Water is also necessary for human settlement.

Recent advances in space science have shown that water is abundant and widespread within the inner solar system. The most accessible source of water in space appears to be the Moon, where water in the form of ice is present in permanently shadowed regions near the lunar poles. The lunar poles are therefore likely to become regions that will see early competition for access. In one effort aimed at tapping these water sources, NASA's Human Exploration and Operations Mission Directorate is supporting research on systems for in-situ resource utilization. Electrolysis is a well-known process for separating hydrogen and oxygen from water. Other technologies, such as hydrogen reduction, can be used with the lunar dust (or regolith). Thus, water trapped in ice on the Moon might one day not only provide water for astronauts and settlements but also might be used to derive hydrogen and oxygen as rocket propellants for onward or return journeys.

Asteroids are found in many places in the inner solar system. The main asteroid belt between the orbits of Mars and Jupiter contains the large majority, but there are many asteroids in orbits that are relatively easy in terms of energy required for spacecraft to access from Earth. Called near-Earth objects, these bodies likely will be the earliest targets for asteroid mining. Asteroids can be identified into categories, based on their composition. Mining plans tend to focus on three types of asteroids: M-type (metallic), C-type (carbonaceous), and S-type (stony). C-type and S-type include bodies that might contain water.

A start-up company focused on asteroid mining, Planetary Resources (which has since been acquired by ConsenSys), has compiled a database—Asterank—of over 600,000 asteroids that might represent mining targets. The United States Geological Survey in 2017 conducted a feasibility study to determine if its traditional methods of conducting mineral resource

assessments on Earth can be successfully applied to asteroids, and determined that they could. The study found that resource deposits on asteroids can be modeled, described, and quantified via methods that are familiar to terrestrial mining operations, and that no novel approaches are required specifically for space resources. It did not, however, address the cost or feasibility of accessing space resources.

## Economics and policy challenges

Understanding the economics of space mining is, at best, inchoate. For example, it is difficult to put credible numbers into investment models, or to understand the impacts on markets, such as the market for platinum, should large shipments start flowing from asteroids. The financial analysis for rocket propellants (hydrogen and oxygen) is more amenable to economic methods, given that the fuel provision costs can be compared with carrying fuel from Earth. As is the case for all space projects, significant capital expenditures would be required before any revenue can be collected. The chief strategist for the asteroid-mining start-up Deep Space Industries recently said in a Bloomberg article that his company expects to "spend tens of millions of dollars before seeing first revenue from our asteroid mining operations." Deep Space Industries subsequently focused its work on developing small water-fueled propulsion systems and was ultimately acquired by a propulsion systems vendor. In considering cost estimations for in-space mining operations, it is important to consider the early stage of planning and development. In general, most activities at the concept or early-stage research phases are not fully defined.

The parameters of a viable business case for lunar-sourced propellants are beginning to come into focus. One commercial rocket company, United Launch Alliance, has offered to buy propellant in space and has set prices at various locations. Recent research at the Colorado School of Mines indicates that it is feasible to mine lunar propellant to meet those prices with acceptable economic returns. Additional demand from governmental entities such as NASA improves the business case. Furthermore, government investment in mining infrastructure may provide the tipping point to attract private investment. Such investment in development of space resources through public-private partnerships is encouraged in the draft 2018 NASA reauthorization bill recently passed out of committee by the House of Representatives. In November 2018 NASA awarded nine Commercial Lunar Payload Services contracts to industry for the development of lunar transportation and delivery-related capabilities.

As commercial business plans for space resources progress, spacefaring countries are using policy and financial tools to competitively position their emerging space industry sectors for growth. Space resources first emerged as a commercial opportunity of target by start-ups based in the United States. Accordingly, the United States was at the forefront of initial policy developments to support this nascent commercial activity. In 2015, Congress passed the U.S. Commercial Space Launch Competitiveness Act (CSLCA). Part of the act, called Title IV, provided US companies the legal right to use resources acquired in space. As noted above, the Outer Space Treaty, under Article VI, requires that nations put into place authorization and supervision regimes to cover activities of their nongovernment organizations, including commercial companies, but there is no international authority that provides an oversight function. Countries that are developing national legislation are in part responding to this obligation.

Following early US efforts spurred by the CSLCA, other countries have moved aggressively to attract and support space resources companies. Japan has created a $1 billion government fund to support domestic space start-ups and is conducting policy reviews specific to enabling commercial activities on the Moon. And Luxembourg, with its passage of a licensing framework, has put into place an extensive policy and financial initiative designed to attract space resource companies.

The policy front has also seen movement. The current US administration has enacted regulatory reform to support and enable commercial space development as a key initiative. And in April 2018, the House of Representatives passed the American Space Commerce Free Enterprise Act, which provides a regulatory framework to support nontraditional commercial space activities, including space resources development. Internationally, recent sessions of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) have included an agenda item on "General exchange of views on potential legal models for activities in exploration, exploitation, and utilization of space resources."

At COPUOS meetings in 2017 and 2018, a wide range of countries made statements regarding their interests in and political positions regarding space resources, with the list including Argentina, Austria, Belgium, Brazil, Canada, Chile, Germany, Greece, Indonesia, Italy, Japan, Luxembourg, the Netherlands, Nigeria, the Russian Federation, the United Arab Emirates, and the United States. Some countries (e.g., Russia and Belgium) expressed a desire to restrict commercial development of these resources until such time as a binding international legal framework is developed. Other countries (e.g., the United States and Luxembourg) indicated that they consider it necessary to move forward on developing domestic regulatory mechanisms in support of national

industry activities in this area. But even with this range of opinions, there appears to be movement toward recognition that space resources utilization is not prohibited under the existing space-related treaty system. Nonetheless, debate at COPUOS reflects diplomatic concerns over a wide range of issues related to space-resources development, including balancing multilateral and domestic legal approaches; ability of developing nations to participate in space resources development; the meaning and interpretation of the terms "exploration," "exploitation," and "use"; and the safety of space resources activities and their effects on the space environment.

Civil society forums are also considering the policy context to enable space resources development. For two decades, the Space Resources Roundtable has explored these issues from a variety of perspectives, including technical matters related to extraction technology and engineering, as well as economic, legal, and policy issues. Considerable policy debate is focused through The Hague International Space Resources Governance Working Group, coordinated primarily by the_Institute of Air and Space Law at Leiden University's law school, in the Netherlands. The working group brings together major stakeholders from government, industry, universities, civil society, and research centers to assess and discuss progress of and issues related to the use of space resources. From these deliberations, the group developed a set of legal building blocks that might form the basis of international and domestic legal frameworks with the specific intent of enabling space resources development. The group has no formal mandate from an existing authority, but its diverse makeup gives it credibility as an expert group in an environment where no formal international regulatory body exists with expertise specific to space resources. The group's expert recommendations can contribute to resolution of the issues raised in discussion at bodies such as COPUOS. The group makes its products available for consideration by both national and multinational forums, and it maintains informal consultative links with those forums.

## Finding policy approaches

Given the economic promise of space resources and the increasing interest on both the domestic and international fronts, it is important to begin establishing a policy framework to enable the creation of a vibrant new industry in a manner in which benefit is broad and not limited to just those directly involved. Here we propose four principles that might guide this policy formation:

*Lessons from terrestrial extractive industries*. There are several areas of precedent when considering policy for space resources development. There is a body of policy and regulation related to extractive industries on Earth and electromagnetic techniques that might be useful as guideposts for space resources use. This type of policy has direct analogies in how terrestrial mining companies operate in exploration and production. Yet policy-makers must recognize that the technical similarities between space resources activities and terrestrial mining are limited—and that the utility of comparing space mining with terrestrial mining may also be limited. Beyond the technical considerations in comparing space mining with terrestrial mining, efforts have also been made to develop governance processes for resources that are not within traditional national boundaries, such as genetic resources and resources located on the deep seabed. Policy approaches to space resources governance should consider lessons—positive and negative—from these regimes as well.

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*Adaptive governance*. Space resources development is a long-term venture with considerable uncertainty. The methods for extracting resources from the Moon and asteroids and processing them into commercially viable materials will evolve as the nascent sector matures. Yet progress requires a policy and legal framework to provide certainty in the legality of the activity, and governments require a policy context to relate commercial activity to civil space programs and international obligations. Policy-makers must adopt a regulatory approach that is incremental—not specifying solutions to challenges that are not fully understood, while establishing the framework to enable space resources development. Elements such as an international registry of space mining activities, separation of legal regimes for lunar and asteroid activities, and noninterference between space mining activities may be needed in the future, but such need should be assessed in consultation with

industry. Accordingly, the Hague Working Group has proposed an incremental approach to policy development based on technological progress, suggesting that it should be "Guided by the principle of adaptive governance … space resource activities should be incrementally addressed at the appropriate time on the basis of contemporary technology/ and practices."

*Benefits arising from space resources development*. In many of the multilateral policy discussions surrounding development of space resources, the question of benefits arises as a key theme. The Outer Space Treaty states that the "exploration and use of Outer Space shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific benefit." Yet discussions of the potential for trillions of dollars of space-based platinum resources or for gigawatts of electricity beamed to Earth each day, combined with the reality that these activities are likely to be initially concentrated in a few spacefaring nations, have created a perception that benefits will be inequitable. Industry and governments have a duty to work together to articulate the potential socioeconomic benefits that will derive from space resources and to develop policy and legal regimes to help address and realize those benefits. In so doing, the concept of benefit must be broadened beyond monetary terms. Established concepts, such as the United Nations' Sustainable Development Goals or lessons from terrestrial extractive industries, may be instructive here. The Hague Working Group has suggested that these benefits "may include, but not be limited to enabling, facilitating, promoting and fostering; development of space science and technology and of its applications; development of relevant and appropriate capabilities in interested States; cooperation and contribution in education and training; access to and exchange of information; incentivization of joint ventures; and exchange of expertise and technology among States on a mutually acceptable basis." Work on elucidation of nonmonetary benefits of space resources development needs to proceed concurrently to technology and business planning efforts.

*Coordination of principles to inform domestic law*. As multiple countries consider and implement domestic policies for space resources, there is need for some level of coordination. Mineral economics and access have historically been a flashpoint of conflict, and the potential of disparate domestic regimes would raise the potential of regulatory forum-shopping and trade and policy tensions. Similarly, developing improved understanding and articulation of the socioeconomic benefits of space resources will be a key element of building commonality in policy frameworks. Information exchanges such as those represented by the Hague Working Group, as well as the work of key multilateral bodies such as COPUOS, are critical in developing this coordination. Space activities are licensed and overseen at the national level. In the current geopolitical context where additional formal space treaties are unlikely to be developed, coordination of principles and sharing of information is critical to ensure that domestic authorities develop regulatory approaches that are informed, effective, and not fragmented (which might lead to industry "flags of convenience" and potential conflict points). Such coordination will promote the collective interest in maintaining the peaceful use of space, while enabling the tremendous benefits promised by capitalizing on space resources.

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Space resources have the potential to spur the next economic revolution for humankind. It is important in the early days of creating this new industrial sector to develop policies, informed by sound scientific and engineering principles, that enable and encourage progress while anticipating some of the challenges ahead.

***Ian Christensen*** *is the director of private sector programs at the Secure World Foundation. The other authors are affiliated with the Colorado School of Mines, where* ***Ian Lange*** *is the director of the Mineral and Energy Economics program,* ***George Sowers*** *is a professor of space resources,* ***Angel Abbud-Madrid*** *is the director of the Center for Space Resources, and* ***Morgan D. Bazilian*** *is the executive director of the Payne Institute and a professor of public policy.*