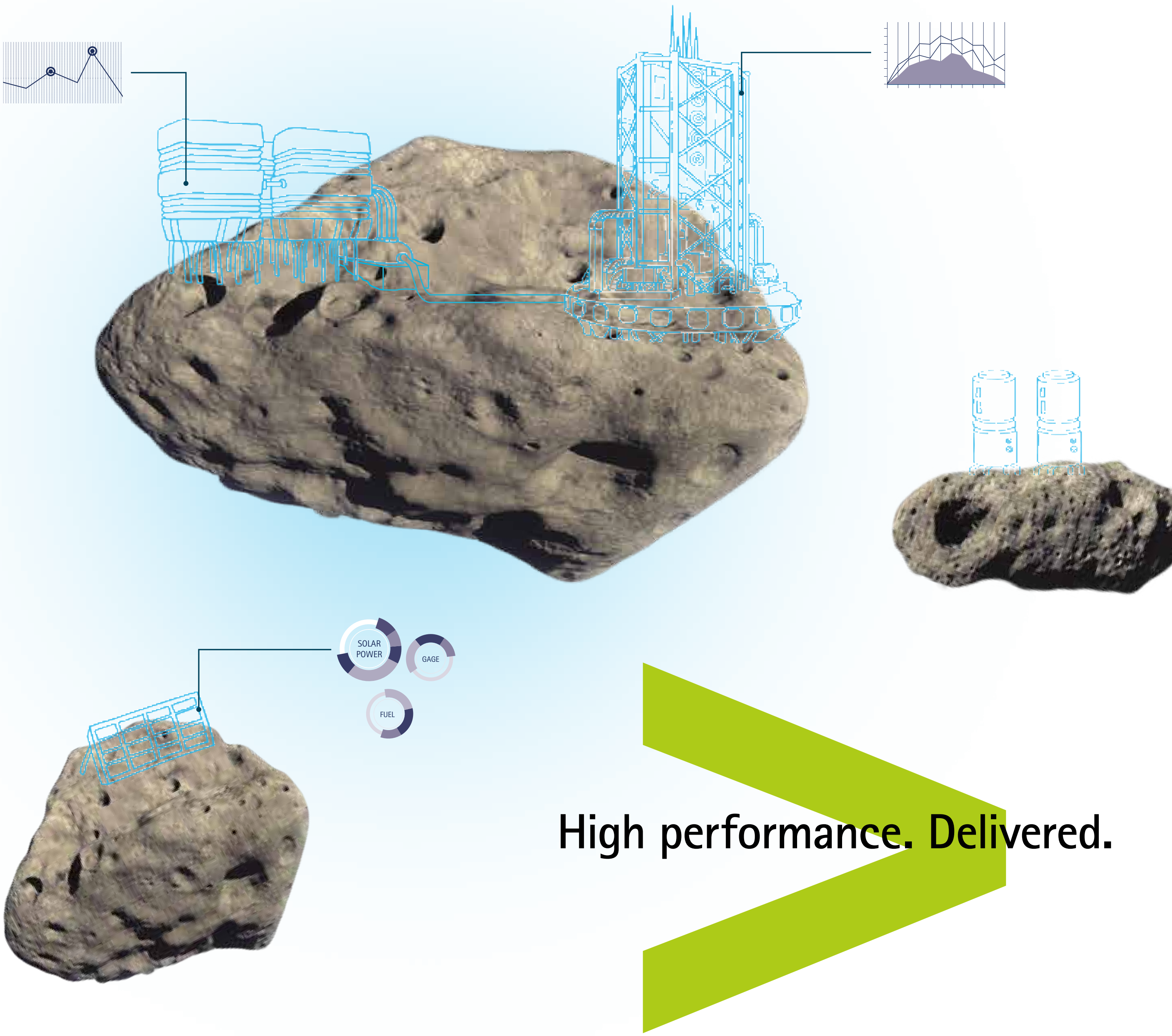
Courage or Capital

The final obstacles for sustainable asteroid mining



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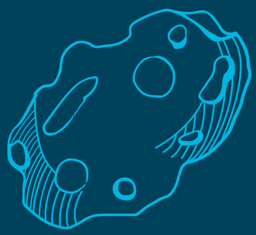
PLANETARY RESOURCES

With the cost to move just one ton of material into low-Earth orbit (LEO) at approximately US$10 million, bypassing launch costs and harnessing the local resources of space for use in space is a high priority for modern space-based enterprises.[1]

If you watch television using a satellite provider, listen to music on satellite radio, follow GPS directions or monitor the weather forecast, then you are already an end consumer of this costly delivery service. More than 600,000 asteroids discovered to date are a gold mine of essential elements that can reduce the cost of these services dramatically. Fortunately, a lengthy trip to the asteroid belt is not required as more than 11,000 asteroids fall into the category of "near-Earth asteroids" (NEA), nearly half of which are easier to return resources from than from our own moon.[2] These asteroids are so rich in materials that just one 75-meter, water-rich asteroid could fuel all 135 Space Shuttle launches conducted over the past 30 years.

What will it take to tap into this tremendously rich and infinite resource? As has been true of any frontier we have tamed through history, it will demand raw guts, determination, and innovative use of existing and new technology to write the next chapter of our evolution.



High-valued resources

The cost to operate in space is dominated by launch costs. According to NASA, delivering a single kilogram (2.2 pounds) of material from the surface of the Earth to high lunar orbit costs a staggering $100,000, more than twice the cost of the same amount of pure gold.[3]

Mining these materials from asteroids will therefore spawn an entirely new industry in space mission services by replacing Earth-sourced materials with those from space and dramatically reducing commercial space-development costs. High-valued resources available in asteroids can be broken down into one of three categories: industrial metals, platinum group metals (or PGMs) and volatiles such as water. Each of these resource groups play a pivotal role in space operations, and their regular availability in orbit would allow for the same kind of 'live off the land' approach that made explorers of Earth's unknowns so successful hundreds of years ago. Imagine if miners during the California gold rush of the 1860s had attempted to carry all of their food, shelter and tools across the country rather than hunt, construct and fabricate locally.

The three major classifications of asteroids are C-type (mostly volatiles with some metal, low density, about 50 percent), S-type (mostly stone and some metal, low density, about 40 percent) and M-type (metal rich, high density, about 10 percent), which all offer attractive end products and pose different risks and challenges.[4]

Metals

From superstructures to semiconductors

Industrial metals are the types of elements that may be used to construct, maintain and repair space platforms, spacecraft and satellites. Iron [Fe], cobalt [Co], nickel [Ni] and titanium (Ti) are abundant within asteroids, and critical for space station and satellite construction. Using industrial processes perfected over hundreds of years, transforming these raw materials into usable alloys such as steel is an exercise in adaptation rather than invention.[5] Normally parts of a space station must be flown up over time, survive the rigors of a short, but incredibly violent 5G+ earthquake-like launch environment, and finally unfold and transform from the compacted rockets from which they arrive. Structures sourced from space, on the other hand, can be fantastically gossamer in nature yet far more massive per unit mass. For example, rather than delivering a two ton system to geosynchronous orbit (GSO) at a cost of $50 million per ton, a 200 kilogram structure from an asteroid could be delivered to GSO at only $100,000 per ton, a 5000x cost reduction.

While industrial metals can be thought of as the base construction items for building a space habitat, the platinum group metals (PGMs) are used in internal circuitry and electronics. PGMs are required for one-in-four manufactured goods on Earth, and consist of platinum [Pt], palladium [Pd], iridium [Ir], rhodium [Rh], ruthenium [Ru], and osmium [Os]. PGMs differ from industrial metals in that they are not only in short supply in space, but also in extremely high demand on Earth due to their scarcity. So while the production of LCDs, electronics and other advanced materials may occur in space in the future, PGMs extracted from asteroids are valuable enough to be returned to Earth and sold into the open market, providing a much needed increase in supply.

Volatiles

From life support to fuel

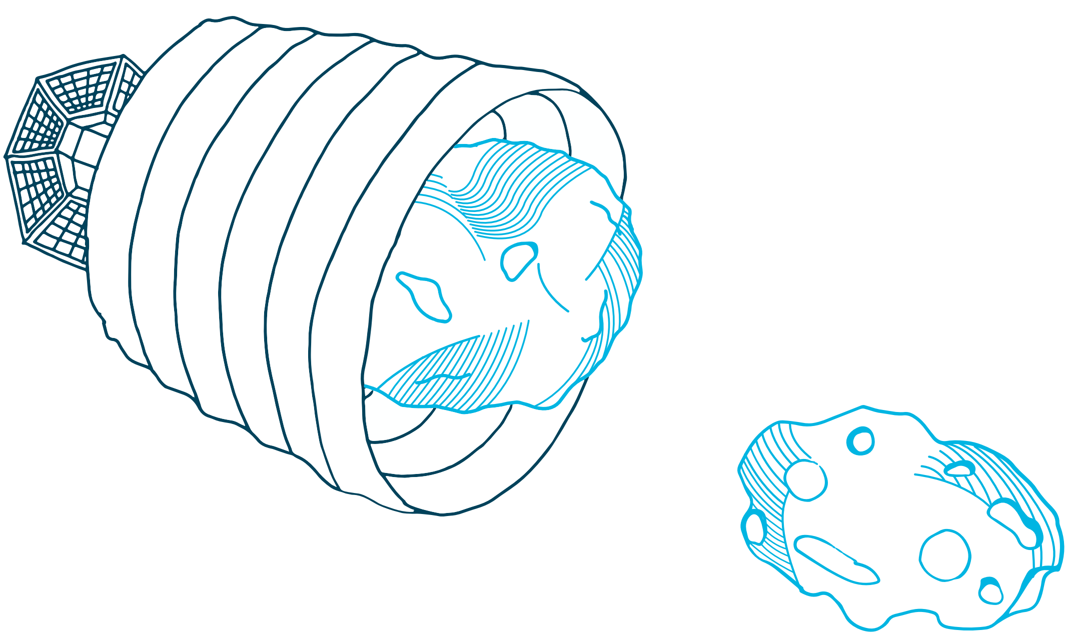
Metals from asteroids will play an essential part in the next phase of our exploration; however, equally important are the volatiles contained within these life-supporting space rocks. Hydrogen [H], carbon [C], nitrogen [N] and oxygen [O] are some of the most coveted materials in the universe for human survival. Refrigerant from nitrogen and hydrogen, carbon-based molecules for agriculture and metallurgy, and organic compounds essential to scientific study and experimentation can all be mined from the abundant deposits in asteroids. Water formed from the hydrogen and oxygen, however, remains the most cherished of all compounds in space exploration and is often the most abundant volatile on asteroids, locked up as water ice and hydrated minerals. Not only can water re-fuel spacecraft, obviating the need for decommissioning or Earth re-entry, but it also can be used for potable water for life support, while shielding from deadly radiation for longer missions to Mars and beyond. The current demand for fuels used in space is estimated at more than $10 billion per year, serving private and government entities alike as they fight to cut down on heavy payloads.[6] The International Space Station alone requires about four tons of water annually for use by the six inhabitants, costing hundreds of millions of dollars each year.

Learning to operate a mine in space

While mining operators on Earth are no strangers to dangerous and inhospitable environments, strategies for extracting ore and volatiles in the microgravity vacuum of space will need to be developed at the intersection of software and hardware.

One such researched solution suggests enclosing an asteroid inside a large, hollow tube and using freely available solar radiation to heat the body to release valuable oxygen, hydrogen and nitrogen.[7] Not only does this method remove the need to transport an asteroid back towards Earth, but it also selectively removes desired products without direct drilling into the body. Forming a large enough cylinder in space (or transporting it there) is a significant challenge, but advances in capability and technology allow small teams to take on activities once reserved for governments in space.

Such a cylinder would save costs in the long term by reducing impact on back and forth flight-towing loads. In fact, the unique environment in space (near absolute zero and a perfect vacuum) would allow the transition of frozen water directly into a gas, which would subsequently condense on the interior of the cylindrical collector. Due to this unique environment and the high resource grades, in some cases asteroid mine development costs could be less than or comparable to traditional mines.



Public policy and resource regulation

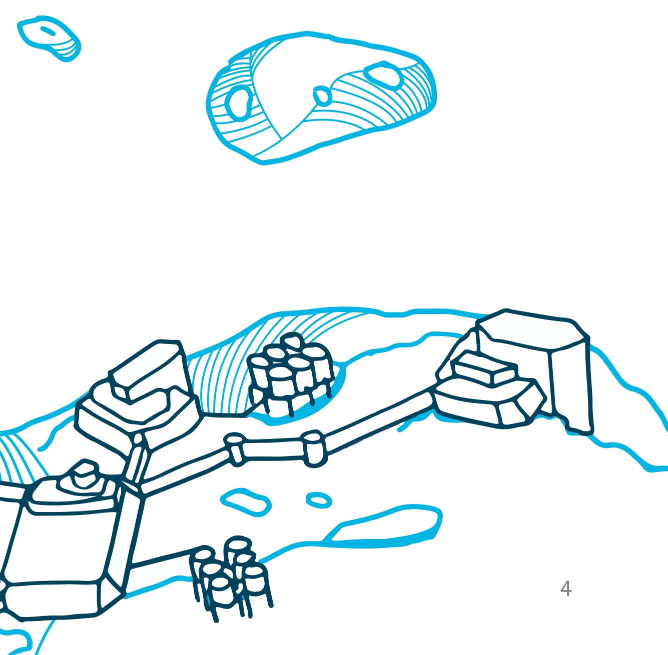
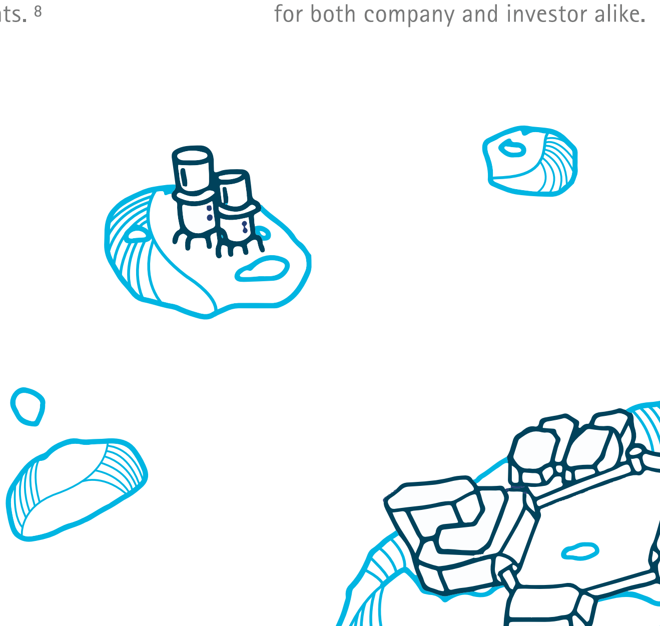
While there is no lack of policy when it comes to space and space exploration, the mining of raw materials is, at this point, largely unregulated by government bodies. As development of the industry progresses, this is unlikely to remain the case, and proper protection of physical assets will be a necessity for a business environment.

Determining who owns certain asteroids, how profits will be taxed and how security concerns will be addressed will provide investors with great certainty. The latest legislation on these issues was ratified internationally in 1967, and clearly updates will need to be made.

Fortunately, the SPACE Act of 2015, which recently passed through the US House of Representatives, begins to define a legal structure in which space mining enterprises can operate. If signed into law by the US Senate and President, the bill would take steps to ensure that, "any asteroid resources obtained in outer space [would be] the property of the entity that obtained such resources", while giving the owner full rights to trade and sell mined resources. While the SPACE Act would be a long way from the kind of global consensus reached in 1967, it shows the kind of commitment needed from world governments to protect asteroid mining companies' investments. [8]

Outside of formal political law, there is also the question of proper classification and valuation of new asteroids. The Joint Ore Reserves Committee (JORC) has long set the standard for evaluating Earth-constrained mining products, but such complex methods of testing may not be possible before the investment to retrieve an asteroid is made. Fortunately, it is unlikely that the same rigor for terrestrial mining will be required, since asteroids are believed to be much more homogeneous in nature and lack the complex mineralization that occurs on Earth.[9]

And because the distance between an asteroid and Earth is only a vacuum, "We can know more about an asteroid millions of miles away than we know about an ore body 50 feet beneath our feet," says President at Planetary Resources, Chris Lewicki. Proper methods of determining the composition and density of potential asteroids will be essential regardless, for both company and investor alike.

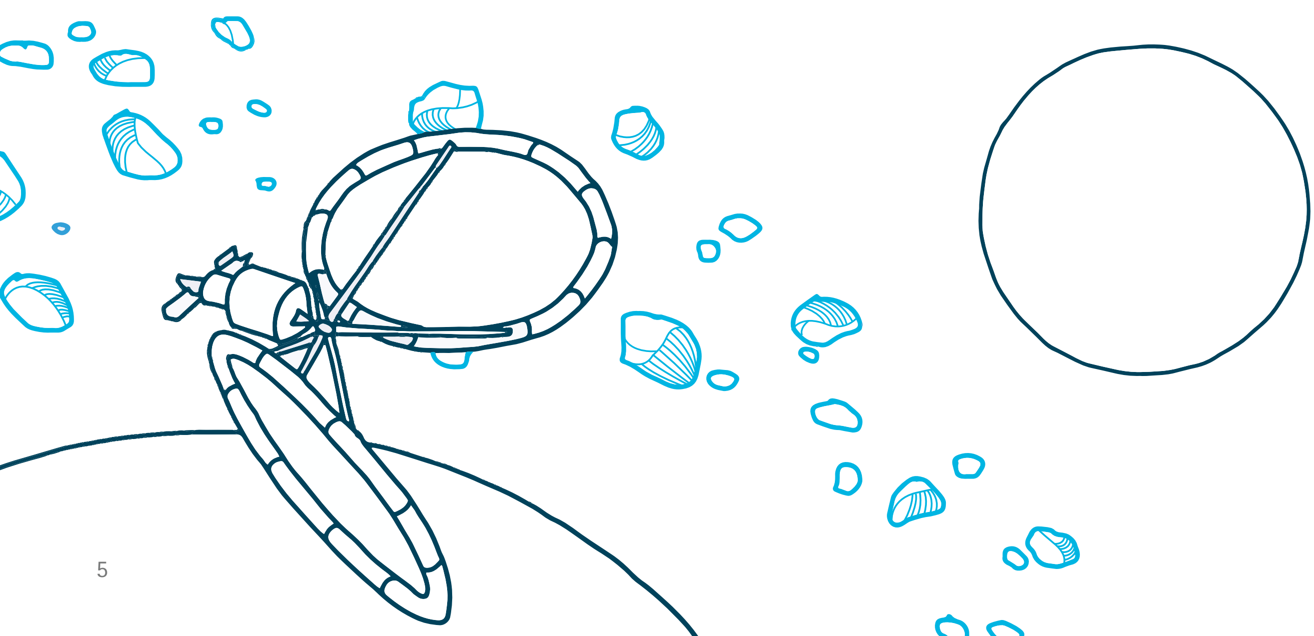



Powering a new series of mining devices

The powering of spacecraft is another area for which humanity has already gained valuable experience. A whole host of different technologies for power generation such as solar and nuclear, power storage such as chemical batteries, and propulsion have all been successfully tested on satellites and launch vehicles.

Choosing the right method of power generation could make or break any near-Earth or deep space mission; however, advances in nuclear battery technology and solar thermal concentrators offer at least two strong options for such missions in the next five or 10 years. Given the abundant, enduring nature of solar power in space, solar thermal concentrators the size of modern space deployables could provide enough energy to extract 50 tons of water from an asteroid in just one week. Such a payload would provide enough water to boost even the largest spacecraft from low-Earth orbit to their final destinations, according to the VP of Global Strategy at Planetary Resources, Frank Mycroft. Nuclear batteries can also be manufactured that are extremely energy dense, less toxic than many traditional batteries and offer a light alternative to other chemical options.[10]

Unfortunately, such batteries are still in the early stages of research, and may not be ready by the time spacecraft need to be tested and assembled. No doubt any power generation method will contain multiple backups, but more development is required on any potential sources to meet the needs of asteroid-bound craft. Once powered, autonomous navigation technologies and precise propulsion systems will control asteroid and craft synchronization, which is more akin to formation flying than a stable orbit. As technology improves, freely available solar energy will likely be the power of choice, reducing costs and design complexity, and echoing our past successes of living off the land.



The final hurdles

Finally, the asteroid mining sector faces the need for capital infusion to get these projects off the ground. Not all capital sources have the courage required to be a part of a highly risky and long-term investment, but with the extremely high potential payout for successful resource acquisition, more and more prominent investors are starting to take note.

Planetary Resources (PRI) counts among its investors world-renowned business magnates, for instance, with a history of transforming traditional industries with great financial success. Strategic investors such as 3D Systems are revolutionizing additive manufacturing with major implications for space development, and investors in PRI like Larry Page, Eric Schmidt and Richard Branson are synonymous with the successful growth of new markets.

These markets are already showing signs of growth: Within the next five years, PRI has set a goal of identifying an asteroid and its resource properties for early mineral exploration customers. In true entrepreneurial fashion, this goal entails a phased development approach with increasingly complex system tests in space every six months. With two orbital tests scheduled for launch in 2015, PRI hopes to demonstrate its core avionics and control systems in low-Earth orbit, before launching the Arkyd 100, an asteroid spotting telescope with full instrumentation and communication. Following successful testing and propulsion demonstrations, a fully functional asteroid prospecting service will be launched with one or more Arkyd spacecraft. With good fortune, by 2020, PRI will be deploying extraction, transport and delivery technologies aboard their Arkyd spacecraft, and officially commissioning mines for their customers.[11]

Asteroid miners would not be the only ones to benefit from such investments however; there are clear benefits to terrestrial mining companies who collaborate with their space bound counterparts. Both traditional mining and asteroid mining are intently focused on autonomous operational capabilities in very harsh environments. For this reason, forward-thinking multinationals in the mining sector are making strategic investments in asteroid mining. For instance Bechtel Corporation, which built the Hoover Dam 75 years ago and is the largest construction and engineering company in the US, has invested in and partnered with Planetary Resources. Software that allows equipment to make decisions independently and new extraction techniques focused on reducing water consumption will benefit all mining parties involved, offering a compelling reason for partnerships and joint ventures.

The market for mining in space is truly one of infinite growth potential. Demand is already starting to rise as we flex our space-bearing muscles, making it only a matter of when, not how. Famed astrophysicist Neil deGrasse Tyson recently took the stage at SXSW in Austin, TX with the message that, "The first trillionaire, in the world, is going to be the person who first mines asteroids."[12] While it might sound like a tale of Aztec gold, the scientific community has produced a 1,400 percent increase in known near-Earth asteroids in the past 15 years alone, with more being discovered every day.[13] The resources and the market are there; what remains are the courage and the brains to break through our final political technological and cost barriers.

Figure 1. Five year outlook.

2015	Demonstrate core avionics and control systems in low-Earth orbit as a proof-of-concept.
2016	Launch the Arkyd 100, an asteroid spotting telescope with full instrumentation and communication technologies proved in the first launch.
2017	Further testing of the Arkyd 100 and propulsion demonstrations for the Arkyd 200 series.
2018	Arkyd 200 and 300 testing, with focus on interdependent Arkyd systems working together.
2019 – 2020	Full deployment of extraction, transportation and delivery technologies in multiple Arkyd spacecraft, with the goal of officially extracting resources for their customers.

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