# Contention 1 Asteroid Mining

#### Commercial asteroid mining is coming now - that helps acquire water for rocket fuel and rare earth metals

Gilbert 21 Alex Gilbert, is a complex systems researcher and a PhD student in space resources at the Colorado School of Mines. "Mining in Space Is Coming." Milken Institute Review, April 26, 2021, [www.milkenreview.org/articles/mining-in-space-is-coming](http://www.milkenreview.org/articles/mining-in-space-is-coming). [Quality Control]

Space exploration is back. after decades of disappointment, a combination of better technology, falling costs and a rush of competitive energy from the private sector has put space travel front and center. indeed, many analysts (even some with their feet on the ground) believe that commercial developments in the space industry may be on the cusp of starting the largest resource rush in history: mining on the Moon, Mars and asteroids. While this may sound fantastical, some baby steps toward the goal have already been taken. Last year, NASA awarded contracts to four companies to extract small amounts of lunar regolith by 2024, effectively beginning the era of commercial space mining. Whether this proves to be the dawn of a gigantic adjunct to mining on earth — and more immediately, a key to unlocking cost-effective space travel — will turn on the answers to a host of questions ranging from what resources can be efficiently. As every fan of science fiction knows, the resources of the solar system appear virtually unlimited compared to those on Earth. There are whole other planets, dozens of moons, thousands of massive asteroids and millions of small ones that doubtless contain humungous quantities of materials that are scarce and very valuable (back on Earth). Visionaries including Jeff Bezos imagine heavy industry moving to space and Earth becoming a residential area. However, as entrepreneurs look to harness the riches beyond the atmosphere, access to space resources remains tangled in the realities of economics and governance. Start with the fact that space belongs to no country, complicating traditional methods of resource allocation, property rights and trade. With limited demand for materials in space itself and the need for huge amounts of energy to return materials to Earth, creating a viable industry will turn on major advances in technology, finance and business models. That said, there’s no grass growing under potential pioneers’ feet. Potential economic, scientific and even security benefits underlie an emerging geopolitical competition to pursue space mining. The United States is rapidly emerging as a front-runner, in part due to its ambitious Artemis Program to lead a multinational consortium back to the Moon. But it is also a leader in creating a legal infrastructure for mineral exploitation. The United States has adopted the world’s first spaceresources law, recognizing the property rights of private companies and individuals to materials gathered in space. However, the United States is hardly alone. Luxembourg and the United Arab Emirates (you read those right) are racing to codify space-resources laws of their own, hoping to attract investment to their entrepot nations with business-friendly legal frameworks. China reportedly views space-resource development as a national priority, part of a strategy to challenge U.S. economic and security primacy in space. Meanwhile, Russia, Japan, India and the European Space Agency all harbor space-mining ambitions of their own. Governing these emerging interests is an outdated treaty framework from the Cold War. Sooner rather than later, we’ll need new agreements to facilitate private investment and ensure international cooperation. What’s Out There Back up for a moment. For the record, space is already being heavily exploited, because space resources include non-material assets such as orbital locations and abundant sunlight that enable satellites to provide services to Earth. Indeed, satellite-based telecommunications and global positioning systems have become indispensable infrastructure underpinning the modern economy. Mining space for materials, of course, is another matter. In the past several decades, planetary science has confirmed what has long been suspected: celestial bodies are potential sources for dozens of natural materials that, in the right time and place, are incredibly valuable. Of these, water may be the most attractive in the near-term, because — with assistance from solar energy or nuclear fission — H2O can be split into hydrogen and oxygen to make rocket propellant, facilitating in-space refueling. So-called “rare earth” metals are also potential targets of asteroid miners intending to service Earth markets. Consisting of 17 elements, including lanthanum, neodymium, and yttrium, these critical materials (most of which are today mined in China at great environmental cost) are required for electronics. And they loom as bottlenecks in making the transition from fossil fuels to renewables backed up by battery storage.

#### However, the legal framework that strikes the best balance of providing economic incentives for mining while preventing unbeneficial land claims requires a doctrine of appropriation – the plan prevents that

Meyers 15 Meyers, Ross. J.D. candidate at the University of Oregon Law School. "The doctrine of appropriation and asteroid mining: incentivizing the private exploration and development of outer space." Or. Rev. Int'l L. 17 (2015): 183. Italics in original. [Quality Control]

The doctrine of appropriation is a reasonable rule for adjudicating asteroid claims, and it could easily be modified to apply to asteroid mining. In the context of water rights, the doctrine of appropriation requires that the claimant be a landowner in order to claim the right to use a water source. It does not make sense, however, for the international community to grant complete ownership over asteroids toa single entity, so the landowner requirement of the rule should be removed. A similar modification would need to be made to the "beneficial use" language of the doctrine. In the context of water rights, an appropriator obtains rights only to water that he or she can reasonably put to beneficial use. The metals contained in asteroids have a high level of marketability. For that reason, a mining entity could potentially put any amount of obtained metal to beneficial use, in the sense that the resources can be sold. This, however, would defeat the purpose of the rule, which is to limit such unreasonable claims. To ameliorate this problem, the doctrine of appropriation could be modified to define "beneficial use "constructively by providing that beneficial use is assumed for any resources that have been removed from the asteroid that the mining entity can reasonably hope to transport to market in a return journey. With the astronomical cost of undertaking a trip to such an asteroid, this modification would limit mining entities to only what they can carry back, thereby leaving the untapped resources available to other entities capable of making the same trip. Considering the size and profitability of metal deposits on asteroids, this modification to the doctrine of appropriation would not be overly burdensome to corporate interests. At the same time, it would satisfy the economic imperative of promoting the rapid development of asteroid resources. By changing the landowner requirement, and qualifying the “beneficial use" language, the doctrine of appropriation would be essentially ready for application to asteroid mining claims. The only other changes necessary would be some additional requirements that are common to other space related provisions, like those found in the Outer Space Treaty of 1968. For example, a reporting requirement or clause guaranteeing asylum for other astronauts. A functional rule might read something like this: *State parties or private entities may, upon actual possession, lay claim to natural resources found on or below the surface of asteroids. Rights to appropriate are given in order of seniority, starting with the first party to land on the surface of the asteroid and establish control over the resources, be it water, methane, metal, or any other beneficial substances. A party will be said to have established control over a resource once he has mined the substance and removed it from the asteroid. A senior appropriator may use as much of the asteroid's resources as he can take from the asteroid and put to beneficial use, and may continue to enlarge his share until another junior appropriator begins to appropriate resources from source for beneficial use. For the purposes of this Agreement, "beneficial use “refers to the amount of resources that an appropriator has removed from the asteroid that the actor may reasonably hope to bring home in a return voyage. Resources in excess of what an appropriator can reasonably hope to transport to market in a single voyage do not qualify as having a beneficial use, and are therefore not yet claimed. This means that the extraction of metal from an asteroid does not serve to provide ownership if the appropriator plans on letting the resources languish until another voyage is undertaken to secure the resources and bring them back to Earth. Junior appropriators receive rights in the source of resources (the asteroid) as they find it, and may prevent the senior appropriator from enlarging his share to the junior appropriator’s detriment under a no-injury rule. No state party will attempt to hinder other parties from landing on or using the asteroid, and parties will assist other entities on an asteroid, should they need emergency assistance. Mining claims on asteroids will be reported to the Secretary-General of the United Nations, and state parties agree to release the location of the asteroid, and any scientific findings to the United Nations, the general public, and the scientific community. In the event that the asteroid is on a collision course with any other celestial body, all state parties agree to follow the course of action suggested by the United Nations. Should the United Nations decide the asteroid must be destroyed, no state party may claim liability for resources contained within the asteroid, but not yet captured. This provision applies only to asteroids as classified by the scientific community, and does not apply to planets, comets, meteorites, or any other celestial body not mentioned.* There is no doubt that asteroids may be extremely beneficial to mankind, both as a source of resources and as a jumping-off point to far off locations in space. The human-race has progressed scientifically and technologically to the point that space travel is within commercial reach, and the need for new international laws governing the ownership of space has never been more apparent. The Outer Space Treaty of 1968made great strides in developing rational rules for space and many of its provisions should be maintained in their original form. However, by allowing ownership of asteroids under the doctrine of appropriation, the international community can incentivize the exploration and development of space in a way that reflects the needs of society in general, without vesting an absolute monopoly in a single entity. The doctrine of appropriation helped drive American westward expansion, and its application to space mining would help drive the human race in its expansion into the space, the final frontier.

#### Asteroid mining offsets terrestrial growth that ruins the environment and enables solar power satellites – both solve climate change

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The mission is essential, Joyce declares, to save Earth from its major problems. First of all, the fictional billionaire wheels in a fictional Nobel economist to demonstrate the actual truth that the entire global economy is sitting on a mountain of debt. It has to keep growing or it will implode, so we might as well take the majority of the industrial growth off-world where it can’t do any more harm to the biosphere.Secondly, there’s the climate change fix. Suarez sees asteroid mining as the only way we’re going to build solar power satellites. Which, as you probably know, is a form of uninterrupted solar power collection that is theoretically more effective, inch for inch, than any solar panels on Earth at high noon, but operating 24/7. (In space, basically, it’s always double high noon). The power collected is beamed back to large receptors on Earth with large, low-power microwaves, which researchers think will be harmless enough to let humans and animals pass through the beam. A space solar power array like the one China is said to be working on could reliably supply 2,000 gigawatts — or over 1,000 times more power than the largest solar farm currently in existence. “We're looking at a 20-year window to completely replace human civilization's power infrastructure,” Suarez told me, citing the report of the Intergovernmental Panel on Climate Change on the coming catastrophe. Solar satellite technology “has existed since the 1970s. What we were missing is millions of tons of construction materials in orbit. Asteroid mining can place it there.”The Earth-centric early 21st century can’t really wrap its brain around this, but the idea is not to bring all that building material and precious metals down into our gravity well. Far better to create a whole new commodities exchange in space. You mine the useful stuff of asteroids both near to Earth and far, thousands of them taking less energy to reach than the moon. That’s something else we’re still grasping, how relatively easy it is to ship stuff in zero-G environments.

#### Without asteroid mining to stop it, climate change causes extinction

David **Spratt 19**, Research Director for Breakthrough National Centre for Climate Restoration, Ian Dunlop, member of the Club of Rome, formerly an international oil, gas and coal industry executive, chairman of the Australian Coal Association, May 2019, “Existential climate-related security risk: A scenario approach,” https://docs.wixstatic.com/ugd/148cb0\_b2c0c79dc4344b279bcf2365336ff23b.pdf

An existential risk to civilisation is one posing **permanent large negative consequences** to humanity which may never be undone, either **annihilating intelligent life** or permanently and drastically curtailing its potential. With the commitments by nations to the 2015 **Paris** Agreement, the current path of warming is 3°C or more by 2100. But this figure does not include “long-term” **carbon-cycle feedbacks**, which are materially relevant now and in the near future due to the **unprecedented** **rate** at which human activity is perturbing the climate system. Taking these into account, the Paris path would lead to around 5°C of warming by 2100. Scientists warn that warming of 4°C is incompatible with an organised global community, is **devastating** to the **majority of** **ecosystems**, and has a **high probability** of not being stable. The World Bank says it may be “**beyond adaptation**”. But an existential threat may also exist for many peoples and regions at a significantly lower level of warming. In 2017, 3°C of warming was categorised as “catastrophic” with a warning that, on a path of unchecked emissions, low-probability, high-impact warming could be catastrophic by 2050. The Emeritus Director of the Potsdam Institute, Prof. Hans Joachim Schellnhuber, warns that “climate change is now reaching the **end-game**, where very soon humanity must choose between **taking** **unprecedented action**, or accepting that it has been left too late and **bear** **the consequences**.” He says that if we continue down the present path “there is a very big risk that we will just **end** **our** **civilisation**. The human species will survive somehow but we will destroy almost everything we have built up over the last two thousand years.”11 Unfortunately, conventional risk and probability analysis becomes useless in these circumstances because it excludes the full implications of outlier events and possibilities lurking at the fringes.12 Prudent risk-management means a tough, objective look at the real risks to which we are exposed, especially at those **“fat-tail” events**, which may have consequences that are damaging beyond quantification, and **threaten** **the** **survival** **of human** **civilisation**. Global warming projections display a “fat-tailed” distribution with a **greater likelihood** of warming that is well in **excess of** **the** **average amount** **of warming** **predicted by** **climate** **models**, and are of a higher probability than would be expected under typical statistical assumptions. More importantly, the risk lies disproportionately in the “fat-tail” outcomes, as illustrated in Figure 1.

# Contention 2 is Innovation

#### Strong commercial space creates a strong foundation for tech innovataion – private appropriation of space is thus key to ALL FUTURE INNOVATION

Joshua Hampson 2017, Security Studies Fellow at the Niskanen Center, 1-25-2017, “The Future of Space Commercialization”, Niskanen Center, https://republicans-science.house.gov/sites/republicans.science.house.gov/files/documents/TheFutureofSpaceCommercializationFinal.pdf

Innovation is generally hard to predict; some new technologies seem to come out of nowhere and others only take off when paired with a new application. It is difficult to predict the future, but it is reasonable to expect that a growing space economy would open opportunities for technological and organizational innovation. In terms of technology, the difficult environment of outer space helps incentivize progress along the margins. Because each object launched into orbit costs a significant amount of money—at the moment between $27,000 and $43,000 per pound, though that will likely drop in the future —each 19 reduction in payload size saves money or means more can be launched. At the same time, the ability to fit more capability into a smaller satellite opens outer space to actors that previously were priced out of the market. This is one of the reasons why small, affordable satellites are increasingly pursued by companies or organizations that cannot afford to launch larger traditional satellites. These small 20 satellites also provide non-traditional launchers, such as engineering students or prototypers, the opportunity to learn about satellite production and test new technologies before working on a full-sized satellite. That expansion of developers, experimenters, and testers cannot but help increase innovation opportunities. Technological developments from outer space have been applied to terrestrial life since the earliest days of space exploration. The National Aeronautics and Space Administration (NASA) maintains a website that lists technologies that have spun off from such research projects. Lightweight 21 nanotubes, useful in protecting astronauts during space exploration, are now being tested for applications in emergency response gear and electrical insulation. The need for certainty about the resiliency of materials used in space led to the development of an analytics tool useful across a range of industries. Temper foam, the material used in memory-foam pillows, was developed for NASA for seat covers. As more companies pursue their own space goals, more innovations will likely come from the commercial sector. Outer space is not just a catalyst for technological development. Satellite constellations and their unique line-of-sight vantage point can provide new perspectives to old industries. Deploying satellites into low-Earth orbit, as Facebook wants to do, can connect large, previously-unreached swathes of 22 humanity to the Internet. Remote sensing technology could change how whole industries operate, such as crop monitoring, herd management, crisis response, and land evaluation, among others. 23 While satellites cannot provide all essential information for some of these industries, they can fill in some useful gaps and work as part of a wider system of tools. Space infrastructure, in helping to change how people connect and perceive Earth, could help spark innovations on the ground as well. These innovations, changes to global networks, and new opportunities could lead to wider economic growth.

#### Space innovation spills over into other sectors and drives STEM education which is crucial to tech literacy

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Increasing economic opportunities in expanding commercial space and non-space sectors: Aside from long-standing commercial satellite services, our expanding space industry, in the process of moving beyond exclusive dependence on limited government budgets and cost-plus contracting, brings with it economic opportunities, not only to those working directly in the space sector but also to non-space actors, including many small businesses. Put another way, an expanding commercial space industry will not only result in high-tech jobs, but also everyday jobs connected to construction, food service, wholesale and retail, finance, and more throughout the communities hosting commercial space companies. 6. Inspiration for STEAM education: Beyond economics, a healthy space sector will continue to inspire people young and old about new frontiers, discoveries, and technologies, and foster interest in STEAM (science, technology, engineering, art, and math) disciplines, which helps create a scientifically literate society able to participate in an increasingly technology-driven world.

#### Humanity is faced with endless global problems – climate change, poverty, war, overpopulation, disease, famine, and there will be far more in the future – the only thing common between these problems is we need strong innovation to solve them

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From a social standpoint, accelerating productivity is not an option but rather an imperative for the future. It is necessary in order to provide the wealth for environmental sustainability, to support an aging population in the industrialized world, and to provide an economic ladder for developing nations. The second area of opportunity for technology lies in its potential to help stabilize global population at 10-12 billion sometime in the twenty-first century, possibly as early as 2075. The key is economics. Global communications, from television to movies to the Internet, have brought an image of the comfortable life of the developed world into the homes of the poorest people, firing their own aspirations for a better quality of life, either through economic development in their own country or through emigration to other countries. If we in the developed world can make the basic tools of prosperity--infrastructure, health care, education, and law--more accessible and affordable, recent history suggests that the cultural drivers for producing large families will be tempered, relatively quickly and without coercion. But the task is enormous. The physical prerequisites for prosperity in the global economy are electricity and communications. Today, there are more than 2 billion people living without electricity, or commercial energy in any form, in the very countries where some 5 billion people will be added in the next 50 years. If for no other reason than our enlightened self-interest, we should strive for universal access to electricity, communications, and educational opportunity. We have little choice, because the fate of the developed world is inextricably bound up in the economic and demographic fate of the developing world. A third, related opportunity for technology is in decoupling population growth from land use and, more broadly, decoupling economic growth from natural resource consumption through recycling, end-use efficiency, and industrial ecology. Decoupling population from land use is well under way. According to Grubler, from 1700 to 1850 nearly 2 hectares of land (5 acres) were needed to support every child born in North America, while in the more crowded and cultivated regions of Europe and Asia only 0.5 hectare (1.2 acres) and 0.2 hectare (0.5 acre) were needed, respectively. During the past century, the amount of land needed per additional child has been dropping in all areas of the world, with Europe and North America experiencing the fastest decreases. Both crossed the "zero threshold" in the past few decades, meaning that no additional land is needed to support additional children and that land requirements will continue to decrease in the future. One can postulate that the pattern of returning land to nature will continue to spread throughout the world, eventually stemming and then reversing the current onslaught on the great rain forests. Time is critical if vast tracts are to be saved from being laid bare, and success will largely depend on how rapidly economic opportunities expand for those now trapped in subsistence and frontier farming. In concept, the potential for returning land to nature is enormous. Futurist and scholar Jesse Ausubel of the Rockefeller University calculates that if farmers could lift average grain yields around the world just to the level of today's average U.S. corn grower, one-half of current global cropland--an area the size of the Amazon basin--could be spared. If agriculture is a leading indicator, then the continuous drive to produce more from less will prevail in other parts of the economy Certainly with shrinking agricultural land requirements, water distribution and use around the world can be greatly altered, since nearly two-thirds of water now goes for irrigation. Overall, the technologies of the future will, in the words of Ausubel, be "cleaner, leaner, lighter, and drier"--that is, more efficient and less wasteful of materials and water. They will be much more tightly integrated through microprocessor-based control and will therefore use human and natural resources much more efficiently and productively. Energy intensity, land intensity, and water intensity (and, to a lesser extent, materials intensity) for both manufacturing and agriculture are already heading downward. Only in agriculture are they falling fast enough to offset the surge in population, but, optimistically, advances in science and technology should accelerate the downward trends in other sectors, helping to decouple economic development from environmental impact in the coming century. One positive sign is the fact that recycling rates in North America are now approaching 65% for steel, lead, and copper and 30% for aluminum and paper. A second sign is that economic output is shifting away from resource-intensive products toward knowledge-based, immaterial goods and services. As a result, although the U.S. gross domestic product (GDP) increased 200-fold (in real dollars) in the twentieth century, the physical weight of our annual output remains the same as it was in 1900. If anything, this trend will be accelerating. As Kevin Kelly, the editor of Wired magazine, noted, "The creations most in demand from the United States [as exports] have lost 50% of their physical weight per dollar of value in only six years.... Within a generation, two at most, the number of people working in honest-to-goodness manufacturing jobs will be no more than the number of farmers on the land--less than a few percent. Far more than we realize, the network economy is pulling us all in." Even pollution shows clear signs of being decoupled from population and economic growth. Economist Paul Portney notes that, with the exception of greenhouse gases, "in the OECD [Organization for Economic Cooperation and Development] countries, the favorable experience [with pollution control] has been a triumph of technology That is, the ratio of pollution per unit of GDP has fallen fast enough in the developed world to offset the increase in both GDP per capita and the growing number of 'capitas' themselves." The fourth opportunity for science and technology stems from their enormous potential to unlock resources not now available, to reduce human limitations, to create new options for policymakers and businesspeople alike, and to give us new levels of insight into future challenges. Technically resources have little value if we cannot unlock them for practical use. With technology, we are able to bring dormant resources to life. For example, it was only with the development of an electrolytic process late in the nineteenth century that aluminum--the most abundant metal on earth--became commercially available and useful. Chemistry unlocked hydrocarbons. And engineering allowed us to extract and put to diverse use untapped petroleum and gas fields. Over the course of history, technology has made the inaccessible accessible, and resource depletion has been more of a catalyst for change than a longstanding problem. Technology provides us with last-ditch methods (what economists would call substitutions) that allow us to circumvent or leapfrog over crises of our own making. Agricultural technology solved the food crisis of the first half of the nineteenth century. The English "steam crisis" of the 1860s, triggered by the rapid rise of coal-burning steam engines and locomotives, was averted by mechanized mining and the discovery and use of petroleum. The U.S. "timber crisis" that Teddy Roosevelt publicly worried about was circumvented by the use of chemicals that enabled a billion or so railroad ties to last for decades instead of years. The great "manure crisis" of the same era was solved by the automobile, which in a few decades replaced some 25 million horses and freed up 40 million hectares (100 million acres) of farmland, not to mention improving the sanitation and smell of inner cities. Oil discoveries in Texas and then in the Middle East pushed the pending oil crisis of the 1920s into the future. And the energy crisis of the 1970s stimulated the development of new sensing and drilling technology, sparked the advance of non--fossil fuel alternatives, and deepened the penetration of electricity with its fuel flexibility into the global economy Thanks to underground imaging technology, today's known gas resources are an order of magnitude greater than the resources known 20 years ago, and new reserves continue to be discovered. Technology has also greatly extended human limits. It has given each of us a productive capability greater than that of 150 workers in 1800, for example, and has conveniently put the power of hundreds of horses in our garages. In recent decades, it has extended our voice and our reach, allowing us to easily send our words, ideas, images, and money around the world at the speed of light. But global sustainability is not inevitable. In spite of the tremendous promise that technology holds for a sustainable future, there is the potential for all of this to backfire before the job can be done. There are disturbing indications that people sometimes turn in fear and anger on technologies, industries, and institutions that openly foster an ever-faster pace of change. The current opposition to nuclear power genetically altered food, the globalization of the economy and the spread of American culture should give us pause. Technology has always presented a two-edged sword, serving as both cause and effect, solving one problem while creating another that was unintended and often unforeseen. We solved the manure crisis, but automotive smog, congestion, and urban sprawl took its place. We cleaned and transformed the cities with all-electric buildings rising thousands of feet into the sky. But while urban pollution was thereby dramatically reduced, a portion of the pollution was shifted to someone else's sky. Breaking limits "Limits to growth" was a popular theme in the 1970s, and a best-selling book of that name predicted dire consequences for the human race by the end of the century. In fact, we have done much better than those predictions, largely because of a factor the book missed--the potential of new technology to break limits. Repeatedly, human societies have approached seemingly insurmountable barriers only to find the means and tools to break through. This ability has now become a source of optimism, an article of faith, in many parts of the world. Today's perceived limits, however, look and feel different. They are global in nature, multicultural, and larger in scale and complexity than ever before. Nearly 2 billion people in the world are without adequate sanitation, and nearly as many are without access to clean drinking water. AIDS is spreading rapidly in the regions of the world least able to fight it. Atmospheric concentrations of greenhouse gases are more than 30% greater than preindustrial levels and are climbing steadily. Petroleum reserves, expected to be tapped by over a billion automobiles worldwide by 2015, may last only another 50-100 years. And without careful preservation efforts, the biodiversity of the planet could become as threatened in this coming century as it was at the end of the last ice age, when more than 70% of the species of large mammals and other vertebrates in North America disappeared (along with 29% in Europe and 86% in Australia). All these perceived limits require innovation of a scope and intensity surpassing humankind's current commitment. The list of real-world problems that could thwart global sustainability is long and sobering. It includes war, disease, famine, political and religious turmoil, despotism, entrenched poverty, illiteracy, resource depletion, and environmental degradation. Technology can help resolve some of these issues--poverty and disease, resource depletion, and environmental impact, for example--but it offers little recourse for the passions and politics that divide the world. The likelihood is that we will not catch up and overtake the moving target of global sustainability in the coming century, but given the prospects for technology, which have never been brighter, we may come surprisingly close. We should put our technology to work, striving to lift more than 5 billion people out of poverty while preventing irreversible damage to the biosphere and irreversible loss of the earth's natural resources.

# Their Case

#### The collision risk of debris is tiny

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More importantly, while our numerical results mimic earlier results (Liou and Johnson, 2005; Walker and Martin, 2004) that stressed the importance of postmission deorbiting, we do not necessarily agree with the claim that the only way to prevent future problems is to remove existing large intacts from space (Liou and Johnson, 2006, 2008). The divergence between our views and those in Liou and Johnson (2006, 2008) is perhaps due to the different performance metrics used. The root causes for alarm in Liou and Johnson (2006, 2008) appear to be the growth rate of fragments and the small increase in the rate of catastrophic collisions over the next 200 years (Liou and Johnson, 2008, Fig. 2). However, the great majority of catastrophic collisions in the SOI do not involve operational spacecraft, and are hazardous only in the sense that the fragments generated from such a collision could subsequently damage or destroy operational spacecraft. Therefore, we introduced the notion of the lifetime risk of an operational spacecraft as the primary performance metric. Our model predicts that the lifetime risk is <5x10^-4 [less than .0005%] over the next two centuries, and always stays <10^-3 [less than .001%] than if there is very high (>98%) spacecraft deorbiting compliance. These risks appear to be low relative to the immense cost and considerable technological uncertainty involved in removing large objects from space, are dwarfed by the ~20% historical mission-impacting (but not necessarily mission-ending) failure rate of spacecraft (Frost and Sullivan, 2004), and could be overestimated if improved traffic management techniques lower future collision risks (Johnson, 2004). Hence, the need to bring large objects down from space does not appear to be as clear cut as suggested in Liou and Johnson (2006, 2008). Nonetheless, our model does not incorporate the possibility of intentional catastrophic collisions (ASAT tests, space wars) that could conceivably occur in the future. In addition, Fig. 5 considers only catastrophic collisions, whereas noncatastrophic intact-fragment collisions could easily disable an operational spacecraft. If the operational lifetime risk is modified to include noncatastrophic collisions with fragments >= 10cm, then the sustainable risk rises by ~50%: it increases from 2.19x10^-2 [.0219%] to 3.09x10^-2 in the base case, and increases from 4.91x10^-4 [.000491%] to 7.94x10^-4 in the full compliance case. Moreover, if fragments >= 1 cm (rather than >= 10 cm) are harmful to spacecraft (Johnson, 2004), then we (as well as other researchers) could be underestimating the risk.