3 August 2009

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Mr. Phil McAlister, Executive Director

Review of United States Human Space Flight Plans Committee
NASA Headquarters, 300 E Street, SW, Washington DC 20024-3210

Dear Mr. Augustine, and honored members of the Committee,

On behalf of all Americans, please accept my thanks for taking up the complex and contentious task of articulating possible future plans for space development.

Why space?

After the nation's second worst economic failure in over a century, the taxpaying public is reexamining priorities. None of your recommendations will receive the support that it requires if the value proposition of space remains as it is: unclear. Cold War motivations are gone and younger generations are otherwise excited.

What compelling reason could possibly make the extraordinarily high price of space travel politically and economically viable?

Rather than the resource-poor moon, or too distant Mars, our national civil space agency should focus on asteroid mineral resources—specifically the platinum group metals. The terrestrial sources of these vital metals are in rapid decline.

Our national civil space agency should demonstrate that asteroid metals mining is technologically feasible and economically compelling. National investments in technological frontiers have produced huge economic returns: the Panama Canal, the intercontinental railroad, the interstate highway system. The nation should now invest in the development of new sources of industrially critical metals.

Profitable asteroid mining would bring necessary industrial resources to the nation—and new tax revenue. This income could be used to develop ever more productive space technologies, that could lead to a growing stream of valuable extraterrestrial resources that would benefit the nation and the world. In these efforts, on-site humans could productively compliment industrial robots.

If space can be shown to offer real value, the public—and their political representatives—will support it. Solve real problems; get real support.

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Cold War hangover

The Cold War, which gripped the country in terrible fear, is over. In 1957, one month after Sputnik, Air Force Chief of Staff Thomas Dresser White declared that "for the first time since 1814, the U.S. homeland was in mortal danger."[1] This fear persuaded the president, congress, and the nation to pay a terrific price for a victory in space.

When Kennedy set the nation on a course to the moon, the United States had suffered a series of space defeats: The U.S. was *not* the first to orbit a satellite, was *not* the first to orbit an animal, was *not* the first to orbit a human, and was *not* the first to send probes by and to the moon. The nation was clearly behind,[2] felt threatened,[3] and believed that winning a race to the moon was worth a very high price.

By taking the lead in this symbolic contest[4] for "prestige,"[5] the U.S. showed the world, and its people, that it could apply scientific knowledge, manage complex technology, and coordinate large engineering teams to solve problems of unprecedented scope.

But Cold War rivals are now actively working to reduce nuclear arsenals.[6] The nation's concerns have shifted from mutually assured destruction to problems that are far more complex and intertwined: achieving stable economic growth along with environmental sustainability. So what are we doing in space today? What will attract new generations? How about securing access to new sources of essential minerals and renewable energy?

Generational priorities

Whether you get your economic news from *The Economist,*[7] the Congressional Budget Office,[8] or the International Monetary Fund,[9] the future looks challenging indeed. The economic drag of the financial crisis, which has precipitated double-digit unemployment in several sectors of the real economy, pales in comparison to the strain that the nation will face over the next few decades as its population ages and retires.

Baby Boomers, who have historically been willing to fork over the bucks for Buck Rogers, may soon put their retirement benefits first.[10] Younger taxpayers are less inclined to pay for "been there done that" goals, like "putting a man on the moon." Americans as a whole are increasingly *less likely* to identify space exploration as the greatest accomplishment of the nation, and "just 5% of Gen Y—whose oldest members were born nearly a decade after Neil Armstrong became the first man to step on the moon—cite space as the nation's greatest achievement."[11]

In 2006, "over two-thirds (68%) [of 18-25 year olds] described themselves as 'Neutral' or 'Not interested' in human missions to the Moon.... **With regard to human missions to Mars, fully 80% were either 'Neutral' or 'Not interested'.**"[12] Generation X and Generation Y are all but absent from NASA's ranks.[13] A 2008 NASA study is blunt: "As a whole, people of Generation Y are not interested in space exploration. This is a FACT."[14]

Drenched in gigabytes of high-definition space-opera video, today's youth find NASA *less* inspiring than the software companies that enable video virtual realties.[15] They realize that computing and communications firms offer real technological frontiers.[16] Today's undergraduates are **more concerned about the environment** than with space.[17]

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When asked to prioritize space development spending, today's net-literate public feels that our civil space programs should (1) Study climate change; (2) Stimulate commerce; (3) Drive science and engineering development; and (4) Enable space colonization.[18] Only one of these involves human space flight; it is their last priority, not the first.

For years, NASA has bemoaned the loss of public support and tried various marketing ploys to convince taxpayers that their programs are worthwhile. These efforts have failed, because the core value proposition is lacking. Rather than trying to force preconceived notions onto the public, our nation's civil space agency needs to listen.

Two Twitter polls are instructive.[19] Both asked the same question. One poll offered only NASA approved responses. The other added two "non official" responses. The question: "What NASA project would you most like to see accomplished?" In the first poll, building a colony on the moon, or Mars, take the lead (29% and 27%). But the second poll showed that the two non-NASA-approved options are more strongly favored: (1) "Provide and/or purchase basic in-space infrastructure to enable private sector development of space" (33%); and, somewhat hyperbolically, (2) "Figure out how [NASA] can obsolete itself by creating a spacefaring society where everyone is capable of being their own NASA" (32%).

Today's netizens want space, but they want it on their own terms, not NASA's.

What if — ?

What if our next 10 year, $100 billion, space program aimed to deliver more than the four "traditional"[20] benefits: (1) to explore and "boldly go"; (2) to earn international prestige and improve national security; (3) to support the careers of American engineers; and (4) to inspire the next generation of engineers and scientists to excel in their studies. What if our next large space program could also deliver $20 to $30 billion worth of platinum group metals (PGMs), the plausible content of a single 500 meter asteroid?[21]

The platinum group metals are increasingly in short supply, and are necessary for today's automotive catalytic converters and for tomorrow's clean running hydrogen fuel cells.[22]

What if, following that space program, which would teach us a great deal about how to effectively mine asteroids[23]—the richest sources of high-value metals in the solar system —a second, five-year, $50 billion, space program managed to *break even,* and return $50 billion worth of critically important industrial minerals to Earth?

What if, in addition to running yet another space program, the nation's civil space agency launched an entirely new ecosystem of self sustaining, space-based industries, with "out of this world" potential for growth? Once PGMs prime the pump, other asteroid resources —including iron, nickel, semiconductors,[24] and volatiles[25] (for fuels)—could enable myriad new industries, such as space-based solar power systems[26] that could radically reduce our reliance on fossil fuels and significantly alter the global climate change equation.

What if the nation's civil space agency unleashed "the genius of private enterprise to secure the United State's leadership in space," as presidential candidate, Barack Obama urged?[27]

This is the way to resolve the quandary of space development: **Make space profitable.**

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Romance v. responsibility

The critical question is how? What goals will hasten space profitability? Neither the moon nor Mars offer the right stuff; only asteroids can get us from here to sustainability.

Space offers vast potential wealth. We need to tap that wealth (and then tax it), so that space development can become truly sustainable. In order to do that, we need to unhinge our antediluvian romance with the goddess in the moon (von Braun's *Frau im Mond*[28]), shift our attention from familiar, resource-poor celestial orbs, and focus on economically meaningful activities in space. We need to develop *profitable* space-based industries.

With rising demands on federal spending—for social security, health care, new sources of environmentally benign energy, and improved education—the United States must focus its space dollars on those space resources that offer the highest possible return. To do otherwise, in an increasingly resource challenged world, is politically irresponsible.

Structuring a space technology revolution[29]

Last century's heroics in space were driven by an impractical, "romantic urge," as von Braun himself admitted, and not a plan to advance the nation's wellbeing. The romantic vision of "men on the moon" was quite compelling for young Werner, who fell in love with that distant milky sphere. He received a telescope on his 13th birthday, and later that year stumbled onto Herman Oberth's *Die Rakete zu den Planetenräumen*[30] (*The Rocket into Interplanetary Space* [1923]). Oberth's text (his rejected doctoral thesis) suggested that von Braun's love was technologically within reach. So inspired, the prepubescent Prussian aristocrat resolved to go to the moon, regardless of the cost.[31]

By succeeding in his life's dream of putting at least a few men on the moon, von Braun demonstrated that three of Oberth's startling propositions from 1923 were in fact true: (1) "With the present state of science and technology it is possible to construct machines that could climb higher than the Earth's atmosphere"; (2) "With further development" such machines could reach orbit or escape Earth's gravity entirely; and (3) These machines could carry humans, possibly without harmful side effects.[32]

Oberth's fourth claim, however, remains as problematic today as was in 1923: (4) "Under certain conditions, the construction of such machines could pay for itself."

Orbiting machines *can* pay for themselves: satellites now offer communication, imaging, and navigational services in billion dollar industries.[33] Each satellite is profitable because of its location, one of three fundamentally valuable space resources:[34]

- Location
- Energy
- Matter

The remaining two fundamental space resources—**energy and matter**—have yet to be harnessed for profitable industrial development.

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The nation has a unique opportunity to increase the wealth of its citizens—and the wealth of the world—by developing the two remaining fundamental space resources: matter (**metals and minerals**) and energy (**solar power**).

Your Committee has a unique opportunity to articulate the robotic and human programs that can bring these untapped resources to a point that profitable commercial enterprises can finance further exploitation without ongoing governmental support. Investments such as these will build broad foundations for a growing set of space-based industries that will in turn generate new tax income streams for the nation, that could be utilized to enhance future space development.

Through forward looking space development policies—similar to those recently adopted for energy technology development (ARPA-E[35])—the nation could use this new income to promote the development of **increasingly advanced space technologies,** so that a growing quantity of space resources can be made available to those living on Earth, and to those who will one day make their living in space, away from the home planet.

From flagpoles to infrastructure

To retain its legitimate moorings in a democratic society, a national agency charged with administering the immensity that we call "space," must articulate the fundamental value proposition of "this new ocean." Otherwise it will lose the support of taxpaying citizens. Lavish spending to plant flagpoles on otherwise unreachable celestial orbs for a few Hollywood moments does not a sound value proposition make. Nor does it significantly increase human knowledge.[36]

Peter Drucker often warned that, while identifying the right tasks can be quite difficult, nothing wastes resources more effectively than brilliantly completing the wrong tasks. If we want to ensure that future Americans are able to enjoy space flight that is **"safe, innovative, affordable, and sustainable,"**[37] popping people off planet as quickly as possible, sending them to mythologically obvious targets, may be *exactly the wrong task*.

It is not that the dream of space—humans travelling to ever more distant destinations—is an unworthy goal for our rambunctious species. Quite the contrary. Just as "nothing in biology makes sense except in light of evolution,"[38] nothing in our species' recent cultural and technological evolution makes sense except in light of future off-planet migrations.[39] **The real issue is strategy.** "How," as they like to say at Lockheed Martin.

Consider the Panama Canal.[40] Nationally mobilized resources were required to bestow upon future generations the multibillion dollar benefits of a water passageway between the two oceans. At the time, the U.S. could have provisioned a "standing army"[41] to drag ships from coast to coast without digging a canal. But no matter how many ships such a team might transport, no matter how proficient they might become, such an imaginary army would never alter the underlying economic framework: A standing army would always be required. Instead, the United States took a more strategic approach. It dug the canal. This meant that no ships would pass until the canal was complete.[42]

Consider the transcontinental railroad or the interstate highway system. This is what our government has done well, on several occasions: **Build new infrastructure.**

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Positive feedback loops

If we want to identify the actions "needed to make human space flight activities most productive and affordable over the long term,"[43] we need to discover a strategy that will precipitate an ecosystem of profitable space-based industries.

But where is Ariadne's thread? What path will allow us to fulfill the vast promise space?

The conundrum of sustainable space development is a "system of systems" problem.[44] It is a complex economic[45] problem. The principal is simple—**profitability** is the mark of a commercial system that contains sufficient positive feedback loops—but the devilish details of any real solution will necessarily encompass a vast meshwork of complexities, from resource management to nonequilibrium thermodynamics,[46] from systems engineering to the sociopolitical evolution of large institutions.[47]

This is the key challenge: If we want to achieve real sustainability, we must create **positive feedback loops.**

Until we do, *The Onion* will carry the real news: "NASA announces plan to launch $700 million into space.... 'Just another step in our long-term goal to put $1 billion on Mars.'"[48] (Or is that $230 billion?[49])

By law and by request: Profitability

For years, it has been clear that commercial development *should* be NASA's top focus. This is not only the conclusion of multiple official reports, including the 2004 Aldridge Commission report,[50] it is also the central tenet of a new generation of entrepreneurial space firms, such as SpaceX, Scaled Composites, Virgin Galactic, and Spaceport America. This group's focus is made explicit in a 2009 white paper by The Commercial Spaceflight Federation, a group of 15 "New Space" firms: "Enabling the development of commercial spaceflight capabilities ... is the single most important action NASA can take."[51]

NASA is in fact *required by law* to "seek and encourage, to the maximum extent possible, **the fullest commercial use of space.**" (The National Aeronautics and Space Act of 1958, As Amended, Section 102 (c)).[52] NASA is not currently operating in accordance with its prime directive.[53]

Neither the Congressional Budget Office nor the Government Accountability Office believe that the agency's current institutional framework will allow it to meet its "cost, schedule, and performance objectives."[54, 55]

More important, there is no expectation that current programs will develop *any* of the solar system's valuable assets.

Real change is required if the nation's civil space agency is to serve the pressing needs of the nation.

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If NASA cannot evolve, and learn to actively support the commercial development of space resources—"to the maximum extent possible"—as the law requires, and serve the interests of emerging profit-making firms, the president must consider a well orchestrated "market exit" for the agency, replacing it with a ***Space Resource Development Agency.***

A threat of imposed market exit may be sufficient to prod the half-century old institution into changing its ways. This threat must be real, however, as institutions often exhibit substantial inertia.[56] Real change may emerge only in the face of existential danger.

In either case—a new agency or a clear willingness to adopt a new direction—commercial development must come to the fore. What then are the most valuable space resources beyond Earth orbit that commercial development might be able to bring to market?

The moon is *not* made of gold[57]

After spending 50 years and hundreds of billions of dollars in necessary but technically adolescent "exploration," we are now well equipped to analyze solar system resources and calculate their economic value, as opposed to their "prestige" value.

The moon is unattractive, not just because Apollo astronauts say that the "current Vision [is] a glorified rehash of what we did 40 years ago,"[58] and that "setting up a [moon] base is absolutely ridiculous."[59] The moon is unattractive because it is **mineralogically poor and gravitationally problematic.** Consisting of post-impact slag,[60] with only a light dusting of mineralogically rich asteroids, the moon is obviously *not* the best celestial source of industrially useful metals.

Lunar gravity is strong enough to require the use of expensive and dangerous rockets for every arrival and departure. Simultaneously, at only one-third Earth-normal gravity, the moon may be unhealthy, perhaps debilitating, for sustained human habitation.[61]

Some have suggested that the moon can offer economically significant quantities of helium-3, a possible fuel for fusion reactors. There is, however, no current demand for this exotic isotope, which may be equally plentiful in asteroid regolith. Even optimistic promoters of fusion energy technology continue to put its possible deployment billions of dollars and decades in the future, even after billions and decades have already been devoted to its attempted realization.[62]

Asteroids: Accessible wealth

Asteroids, on the other hand, offer rich deposits of metals that are currently in demand. They generate only very small gravitational effects, so expensive, high-powered rockets are not required. Asteroids also offer structural materials (e.g., iron, nickel, and silicon), volatiles (which can be used for in-space propulsion), and semiconductors. These can be used to build a wide range of evolving infrastructure, including, in the fullness of time, spinning habitats that can precisely simulate biologically benign, Earth-normal gravity.[63]

Thanks to several Hollywood blockbusters, the potential dangers of an asteroid impact are widely known.[64] But the fact that **asteroids contain high value minerals** that are critical for industrially development is less widely known.

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This knowledge gap may be partially addressed next June, when the *Hayabusa,* a Japan Aerospace Exploration Agency (JAXA) spacecraft, is expected to return the first asteroid samples to Earth.[65] (The European Space Agency (ESA) is planning a similar mission.[66]) Nearly 1,000 near-Earth asteroids have been identified that are easier to reach than the moon (requiring a lower delta-V).[67] Thousands more of these "very near-Earth asteroids" (VNEAs) are expected to be identified in the next 10-20 years, as new sky-survey telescopes (Pan-STARRS and the LSST[68]) register **500,000 NEAs**.[69]

With the *Hayabusa,* JAXA has shown, at a cost of "about $170 million,"[70] that asteroid materials can be reached and returned to Earth. The number of potential targets is now increasing exponentially. Fine, but is there demand for these materials? Yes, quite a bit.

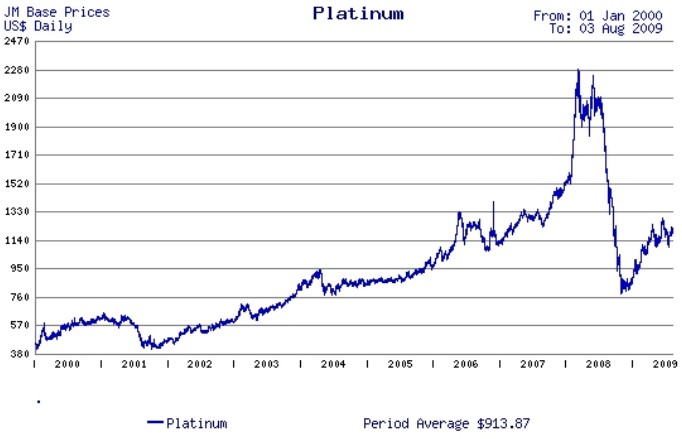
We are being made increasingly aware that Earth's resources are limited. Concern about "peak oil" has become widespread: "A debate rages over the precise date of peak oil, [but] this rather misses the point, when what matters—and matters greatly—is the vision of the long remorseless decline that comes into sight on the other side of it," as Colin Campbell, founder of the Association for the Study of Peak Oil, points out.[71]

Yet o*il is only one* critical industrial resource that may be at or near peak. The U.S. Geological Survey reports that **the United States imports 100% of 18 minerals that are essential for industry.**[72] In 2008, the National Academies identified the platinum group metals (PGMs)—used in automotive catalytic converters and fuel cells—as the "most critical" for current industrial development.[73]

"There is simply not enough platinum and rhodium going round on this planet to satisfy the collective demand of automotive emission-control systems," as Johannes Schwank, professor of chemical engineering at the University of Michigan, explained in 2007.[74] Some projections show terrestrial platinum reserves depleted within a few decades.[75]

More than 75% of the world's platinum—and more than 85% of the rhodium—comes from a single geological feature in South Africa, the "Bushveld Complex."[76] Nearly half of all available platinum, and 84% of all rhodium, is used for automotive catalytic converters.[77]

Last year's commodity bubble drove prices to record highs (platinum: over $2,000/oz; rhodium: over $10,000/oz). Prices crashed at the end 2008, but are now rising again as the economy recovers (platinum: ~$1,200/oz; rhodium: ~$1,400/oz).[78]



Other vital high-tech metals, including gallium, indium, and hafnium, are now being reported as "potentially running short ... within the next decade."[79]

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A single asteroid can contain more than a year's worth of current platinum production—worth tens of billions of dollars—as well as other high-value metals such as gallium, indium, and other rare earths, and literally *tons* of iron and nickel.[80]

Critically, platinum shortages are already effecting U.S. energy policy decisions.

Hydrogen fuel cells are widely understood to "reduce greenhouse gas emissions faster than any other [automotive] technology," and yet funding for Department of Energy hydrogen research programs was cut earlier this year, due to the relative unavailability—"the high cost"—"of precious-metal [platinum group metal] catalysts."[81]

A national civil space agency could—and should—build upon this demand for industrially critical metals, and formulate an easy to understand motto that captures its core purpose: ***"We bring essential resources from space to Earth."*** Or, today, as the agency develops and runs demonstration projects that show the technical feasibility of asteroid mining: *"We make it possible* to bring essential resources from space to Earth."

Space-based solar power

In the long term, space-based solar power (SBSP) systems in Earth orbit are likely to have **much greater economic and environmental significance** than the PGMs. Near term, SBSP could be used to help insure national security, by providing electricity directly to globally deployed troops and for disaster relief.[82] Eventually, SBSP could free us from our dependence on fossil fuels; its potential is essentially limitless.[83]

The nation's civil space agency should help the *near-term* growth of this nascent industry by building and deploying demonstration units. It could help the *long-term* growth of SBSP by developing asteroid mineral mining, refining, and transportation technologies to deliver asteroid materials to Earth orbit. With high launch costs, it makes good economic sense to bring asteroid minerals into Earth orbit so that they can be used to build the next-generation of Earth-orbiting, satellite infrastructure: large scale SBSP.[84]

SBSP is also an attractive opportunity for international cooperative development.[85]

The enduring value of opposable thumbs

What should a national civil space agency do to help enable the profitable commercial development of space energy and minerals, and thus benefit the nation and the world?

Building demonstration SBSP systems is one good use of federal resources. Drawing asteroid mineral resources into the economy will be more challenging. Asteroid mining will require travelling beyond low Earth orbit and new technology. Both efforts could benefit from application of the opposable thumbs and adaptive brains of our favorite species. What a great opportunity to demonstrate the value of human space flight!

Recommendations

The following lists identify two sets of recommendations, one for our national civil space agency and one for the engagements of that agency to enable profitable asteroid mining.

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Recommendations: National civil space agency

A national civil space agency should serve the needs of the nation. To do this, it should purchase commercial products and services whenever possible; applaud the success of entrepreneurial space ventures;[86] promote international commercial cooperation; and harness competition and evolution to develop new technologies and agile processes.

To promote the development of space resources, the nation's civil space agency should work in cooperation with the USGS[87] and the U.S. State Department.[88] It should also:

1. Make safe access to space—space security—the agency's *operational priority*.

> "We can define **'space security'** as *the ability to place and operate assets outside the Earth's atmosphere without external interference, damage, or destruction*.... This is a fundamentally *political* task.... [The] most useful framework for analyzing the past, present, and future of these issues is not a traditional military-strategic one, but instead the interdependent concept of **environmental security**."
> —James Clay Moltz (2008)[89]

   ▪ Without safe access, all bets are off. Our civil space agency needs to engage all participants—internationally and across all domestic agencies and departments that work with space assets—to identify the most effective actions that will ensure the nation's long-term access to space. Specifically, the dangers of orbital debris[90] and the weaponization of space,[91] must be proactively counteracted.

2. Make profitable development of space resources the agency's *programmatic priority*.

   ▪ Establish asteroid mining and SBSP as central to the agency's mission.

   ▪ Design space science programs that specifically enable space commerce.

   ▪ Encourage other nations to make their own practice lunar visits, while inviting them to work with the U.S. to develop real—that is valuable—space resources.

   ▪ Explain the logic of sustainable space development to the nation's tax payers: Only by establishing economically profitable activities can we achieve genuine sustainability in space. Asteroid mining and solar power are the most promising candidates for establishing commercial sustainability. Bases on the moon or on Mars cannot be made economically sustainable with current technology; this may change following the profitable development of accessible space resources.

3. Deploy human astronauts only when they can be shown to offer clear added value.

   ▪ Space is dangerous. Humans will always be at risk away from the home planet, until we can build safe, reliable habitats.[92] One of the benefits of developing an aggressive, multi-launch, robotic effort to prospect and then mine asteroids is that these programs will help move us up an unavoidably steep learning curve.

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Recommendations: Asteroid mining

To promote the profitable development of asteroid resources, the nation's civil space agency should carry out a multi-pronged effort, possibly including the following actions:

1. Fund the development and utilization of sky-survey telescopes.

    ▪ Support sky survey programs, such as Pan-STARRS and the LSST.[93]

2. Deploy 100+ robotic spacecrafts to survey the mineral content of 200 to 300+ NEAs.

    ▪ Purchase a hundred or more modular, relatively inexpensive ($20 million each) spacecrafts, evolved from the prize winning, CubeSat-based *Houyi*,[94] which was designed to "tag and track" the potentially hazardous asteroid *Apophis*. Total mission cost: $16 million. Deploy in waves; each spacecraft rendezvous with, surveys, and flies on to one or two additional near-Earth asteroids (NEAs).

3. Run competitions to develop asteroid mineral extraction and processing technologies.

    ▪ Run competitions similar to the Lunar Regolith Excavation Challenge,[95] and award prize money for the most effective robots that can: (1) Withstand launch to low Earth orbit; (2) Process a mass (100 kg) of simulated asteroid regolith that contains platinum group metals in the form and proportions anticipated; (3) Extract the valuable metals; and (4) Return them safely to Earth.

4. Deploy a half-dozen robotic miners to the most attractive near-Earth asteroids.

    ▪ Purchase a pair of scaled-up, demonstration robotic miners from each of the top three qualifying winners of the asteroid regolith challenge, and deploy these to the most attractive near-Earth asteroids, based on the survey results.

5. Purchase transportation for astronauts to low Earth orbit (LEO) and to NEAs.

    ▪ Send teams of astronauts to LEO during regolith processing competitions and to asteroids during first demonstration mining efforts. Astronauts will monitor, evaluate, diagnose, and repair robotic miners in orbit, and at the asteroids,[96] to support the eventual goal of autonomous robotic operations.[97]

6. Lead international negotiations to secure an asteroid property rights[98] regime treaty.

    ▪ The 1967 Outer Space Treaty defined all celestial bodies as *res communis;* they cannot be appropriated.[99] Subsequent efforts to establish extraterrestrial property rights have failed; an equitable and entrepreneurial treaty is needed.[100] Interested parties might agree to a claim-registration process that allows claims for small objects (≤ 10 km asteroids and comets), while postponing agreements on larger object (planets and moons). Such a treaty could be based on restricted serial claims: one claim is honored from one entity at a time; subsequent claims being granted only after existing claims have been worked, the extracted minerals brought to market, and all related scientific data published on the Web.

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A national civil space agency must be able to show how their efforts benefit the nation. The clearest opportunity available is the economic development of space resources. Commercial profitability is the key to establishing sustainable space development.

Whenever it is possible to show that humans will add real value to programs that develop solar system resources—by extracting asteroid minerals or by building space-based solar power systems—astronauts should certainly be included. Otherwise, we should not put their lives at risk while we learn how to operate safely and effectively in the dangerous vastness of space that, through careful planning, and luck, our children may one day freely inhabit.

Thank you again for taking on this challenging and important work.

Sincerely yours,

William BC Crandall
President & Director

bc.crandall@abundantplanet.org

This letter: http://abundantplanet.org/letters

Abundant Planet is a public benefit, 501(c)3, California corporation. We promote the development of asteroid resources and their *profitable* use in space and on Earth

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[1] White, Thomas Dresser. At the National Press Club, Washington, DC. 29 December 1957. As quoted in Moore, Mike. *Twilight War: The Folly of U.S. Space Dominance*. Oakland, CA: The Independent Institute. 2008. p. 4.

[2] "To be sure, we are behind, and will be behind for some time in manned flight. But we do not intend to stay behind, and in this decade, we shall make up and move ahead." Kennedy, John F. Rice University, Houston, Texas. "We choose to go to the moon." 12 September 1962. <http://www.historyplace.com/speeches/jfk-space.htm>

[3] "In the weeks and months after Sputnik many Americans seemed to be seized not only with a sudden worry that our defenses had crumbled, but also ... that our entire educational system was defective." Dwight D. Eisenhower. *The White House Years: Waging Peace (1956-61)*. New York: Double Day. 1965. p. 217. Quoted by Moltz, James Clay. *The Politics of Space Security: Strategic restraint and the Pursuit of National Interests*. Stanford, CA: Stanford University Press. 2008. p. 92.

[4] "Intuitively, not consciously, Kennedy had chosen another form of military contest, an oddly ancient and archaic one....: 'single combat.' The best known of all single combats was David versus Goliath." Wolfe, Tom. "One giant leap to nowhere." *The New York Times*. 19 July 2009. <http://www.nytimes.com/2009/07/19/opinion/19wolfe.html>

[5] "It is vital to establish specific missions aimed mainly at *national prestige*.... [Such] non-military, non-commercial, non-scientific but 'civilian' projects such as lunar and planetary exploration [could help] the battle along the fluid front of the cold war." NASA Administrator James Webb and Secretary of Defense Robert McNamara. "Recommendations for Our National Space Program: Changes, Policies, and Goals. A secret report to Vice President Lyndon Johnson." 8 May 1961 (declassified). p. 8. Quoted by Moltz. *The Politics of Space Security*. 2008. p. 108. (Emphasis added.)

[6] U.S. State Department. "Joint Statement by President Barack Obama of the United States of America and President Dmitry Medvedev of the Russian Federation on Nuclear Cooperation." 6 July 2009. <http://www.state.gov/p/eur/rls/wh/125655.htm>

"President Barack Obama has moved nuclear deterrence to the top of the national-security agenda—and in his dealings in the past month with Iran, North Korea and Russia, revealed the issue to be an organizing principle to his foreign policy." Spiegel, P. "Obama puts arms control at core of new strategy." *Wall Street Journal*. 15 July 2009.

[7] "Not since the second world war have so many governments borrowed so much so quickly or, collectively, been so heavily in hock.... Worse, today's borrowing binge is taking place just before a slow-motion budget-bust caused by the pension and health-care costs of a greying population. By 2050 a third of the rich world's population will be over 60. The demographic bill is likely to be ten times bigger than the fiscal cost of the financial crisis." "The biggest bill in history." *The Economist*. 11 June 2009.

[8] "Under current law, the federal budget is on an unsustainable path—meaning that federal debt will continue to grow much faster than the economy over the long run. Although great uncertainty surrounds long-term fiscal projections, rising costs for health care and the aging of the U.S. population will cause federal spending to increase rapidly under any plausible scenario for current law." Congressional Budget Office. "The Long-Term Budget Outlook." June 2009. <http://www.cbo.gov/ftpdocs/102xx/doc10297/06-25-LTBO.pdf>

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[9] The "recession is not over and the recovery is likely to be sluggish.... [The] advanced economies as a group are still projected not to show a sustained pickup in activity until the second half of 2010." IMF. "World Economic Outlook Update." 8 July 2009. <http://www.imf.org/external/pubs/ft/weo/2009/update/02/pdf/0709.pdf>

[10] Congressional Budget Office. "The Long-Term Budget Outlook." June 2009.

[11] Pew Research Center. "'One small step' no longer seen as such a giant leap for America." 15 July 2009. <http://pewresearch.org/pubs/1283/fewer-see-space-or-science-as-top-american-achievement>

[12] Dittmar, Mary Lynne. "Engaging the 18-25 generation: Educational outreach, interactive technologies, and space." American Institute of Aeronautics and Astronautics. 2006. <http://www.boeing.com/defense-space/space/constellation/references/reports/Engaging_the_18-25_Generation.pdf>

[13] Henning, Garth and Richard Leshner. "The state of the next generation of explorers." NASA Headquarters. 2008. <http://www.opennasa.com/wp-content/documents/NexGenExplorers.pdf>

[14] Skytland, Nicholas and Garret Fitzpatrick. "Generation Y Perspective." In Davidian, Ken, et. al. *Proceedings of the Next Generation Exploration Conference-2*. 2008. NASA CP–2008-214583. <http://ngec.arc.nasa.gov/files/NGEC-2_Proceedings.pdf>

[15] "Star Trek ruined an entire generation, maybe two... maybe three. [They have been] ruined to expect excitement, glamour, interspecies interaction, and a host of things that space exploration in the real universe simply does not provide. Ruined. Expectations set too high." Hale, Wayne. "Real life is not like Star Trek." *NASA Blogs*. 10 July 2009. <http://blogs.nasa.gov/cm/blog/waynehalesblog/posts/post_1247262291204.html>

[16] A recent report suggests that "in a 2009 survey of undergraduates, NASA was among the top 10 most admired private and public sector employers." While true, the *top three* were Google, Walt Disney, and Apple Computer. NASA was ranked 8th. <http://www.wetfeet.com/universumrankings/Undergrad-2009.aspx> As referenced in Committee on the rationale and goals of the U.S. civil space program. "America's future in space: Aligning the civil space program with national needs." Washington, DC: The National Academies Press. 2009. p. 28. <http://cart.nap.edu/cart/deliver.cgi?&record_id=12701>

[17] "Close to half [of incoming freshmen] (45.3 percent) believe it is 'very important' or 'essential' to adopt green practices to protect the environment, [and] 74.3 percent believe "addressing global warming should be a federal priority." UCLA Higher Education Research Institute. "Annual Freshman Survey." January 2009. <http://media-newswire.com/release_1084936.html>

[18] Committee on the rationale and goals of the U.S. civil space program. "America's future in space." 2009. p. 66.

[19] <http://twtpoll.com/v84ywn> <http://twtpoll.com/v93n8v>

[20] These four "space values" were offered by Eisenhower's Science Advisory Committee in 1958 (<http://history.nasa.gov/sputnik/16.html>) and have served as the basis of nearly all such documents ever since, including the last administration's "vision."

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[21] Based on 2007 prices, a 500 meter diameter asteroid, of a common type, contains platinum group metals valued at $19 to $26 billion, depending on asteroid density. <http://abundantplanet.org/files/Asteroid-Value-2007-prices--2009-08-03.pdf>

[22] "A fuel cell works by catalysis, separating ... electrons and protons of the reactant fuel ... converting them to electrical power. The catalyst typically comprises a *platinum group metal*.... Waste products [are] typically simple compounds like water and carbon dioxide" (emphasis added). Wikipedia. <http://en.wikipedia.org/wiki/Hydrogen_fuel_cells>

[23] Currently, the best short technical overview of the field is offered by Shane Ross, in a Cal Tech Space Industry Report, "Near-Earth Asteroid Mining." 2001. <http://www.cds.caltech.edu/~shane/papers/ross-asteroid-mining-2001.pdf>

John Lewis, an early proponent of asteroid mining, gave an introductory lecture in 2006. The slides from his talk, "Asteroid Exploration and Exploitation," are online: <http://ngec.arc.nasa.gov/files/ngec_proceedings/speakers/Lewis_Asteroids.pdf>

A 2004 NASA bibliography, "Recovery and Utilization of Extraterrestrial Resources," <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040045217_2004046541.pdf> indicates that NASA has not published a study of asteroid mining for over 15 years. The most recent, edited by Mary Fae McKay, et al., "Space Resources," NASA SP-509, 1992, sites two previous reports from the 1970s: Johnson, Richard and Charles Holbrow, editors. "Space Settlements: A Design Study." NASA SP-413. 1977. And O'Neill, Gerard, et al., editors. "Space Resources and Space Settlements." NASA SP-428. 1979. <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930007681_1993007681.pdf> <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770014162_1977014162.pdf> <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790024054_1979024054.pdf>

[24] NEAs offer several semiconductors: antimony, arsenic, gallium, germanium, indium, phosphorous, selenium, and tellurium. Ross. "Near-Earth Asteroid Mining." 2001. p. 7.

[25] Some "objects in the asteroid belt have incorporated significant amounts of water ice (and possibly other volatiles) during their formation in the early stages of the solar system." Mousis, Olivier, et al. *Monthly Notices of the Royal Astronomical Society* 2008;383(3):1269-1280. <http://perso.utinam.cnrs.fr/~mousis/papier32.pdf>

[26] Wikipedia. <http://en.wikipedia.org/wiki/Space-based_solar_power>

[27] Obama for America. "Advancing the frontiers of space exploration." <http://www.barackobama.com/pdf/policy/Space_Fact_Sheet_FINAL.pdf>

[28] Von Braun's love affair with the moon, and Herman Oberth's role as a consultant for Fritz Lang's 1929 film, *Die Frau im Mond,* is described in the great biography by Michael Neufeld. *Von Braun: Dreamer of Space, Engineer of War*. New York: Vintage. 2007.

[29] Adapting the fine phrase used by Charles Weiss and William B. Bonvillian as the title of their book, *Structuring an Energy Technology Revolution* (Cambridge, MA: The MIT Press. 2009), which present a "new innovation policy framework for energy technology [that is] applicable to technological innovation in sectors of similar complexity." p. 35.

[30] Oberth's book, *Die Rakete zu den Planetenräumen,* was "the first serious proposal for a manned space station to appear in scientific literature rather than fiction." <http://history.nasa.gov/SP-4225/documentation/early-station/early.htm>

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[31] Von Braun's Faustian bargain with the Nazis, hidden during his career as America's heroic "space scientist," is now well known. At the close of World War II, hundreds of his weapons fell on London, Paris, and Antwerp, killing thousands. Documents show that Von Braun, as an SS *Hauptsturmführer*, authorized transfers of 300 "technically qualified" prisoners from the Buchenwald *Konzentrationslager* to Dora, the mountain-tunnel production site of his A-4 (V-2) rocket. This order would seem to "put von Braun in violation of the Nuremberg war crimes standard regarding forced labor [which was later applied to von Braun's supporter] Albert Speer." Neufeld. *Von Braun*. p. 122, 179.

[32] Oberth. *Die Rakete*. As quoted in Neufeld. *Von Braun*. p. 24.

[33] "Overall worldwide [satellite] industry revenue growth was 19% from 2007 to 2008, compared with a 15% increase from 2006 to 2007." Worldwide revenues for 2008 exceeded US$140 billion. Futron Corporation. "State of the Satellite Industry Report." June 2009. <http://www.futron.com/pdf/resource_center/reports/2009SSIR.pdf>

For example, this July, Arianespace launched a nearly 7,000 kg communications satellite into orbit intended to support satellite phones: "the 31st consecutive success for Ariane 5." <http://www.arianespace.com/news-mission-update/2009/609.asp>

[34] A fourth resource is of course critical for securing these three more tangible resources: data/information/knowledge. This ingredient is not immediately marketable, nor a very fungible commodity, but it is essential for all positive evolution. "Progress in exploiting the existing stock of knowledge [depends] first and foremost on the efficiency and cost of *access* to knowledge.... Language, mathematical symbols, diagrams, and physical models are all means of reducing access costs." Mokyr, J. *The gifts of Athena: Historical origins of the knowledge economy*. Princeton, NJ: Princeton University Press. 2002. p. 7.

[35] "ARPA-E is a bold concept that will provide access to the funding needed to bring the next generation of energy technologies to fruition." <http://arpa-e.energy.gov>

[36] "Returning Americans to the moon and landing on Mars would have a powerful symbolic significance, but it would constitute *only a small step in the advancement of knowledge,* since much will already be known from exploration with the robotic precursor probes that are necessary to guarantee the safety of any human mission" (emphasis added). "The Moon-Mars Program." American Physical Society. November 2004. <http://www.aps.org/policy/reports/popa-reports/upload/moon_mars.pdf>

[37] Charter of the Review of U.S. Human Space Flight Plans Committee. Section 3. <http://www.nasa.gov/offices/hsf/about/charter.html>

[38] Theodosius Dobzhansky, *American Biology Teacher,* 1973.

[39] Such ideas are older than the space age. Two examples:

One from 1957: "By expanding through the universe, man fulfills his destiny as an element of life." Ehricke, Krafft. "The anthropology of astronautics." *Astronautics: A publication of the American rocket society*. November 1957. p. 28.

One just delivered to your committee: "The goal of the human spaceflight program should be to increase the survival prospects of the human race by colonizing space." "A goal for the human spaceflight program." J. Richard Gott, III. Princeton University. <http://www.nasa.gov/pdf/368985main_GottSpaceflightGoal.pdf>

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[40] McCullough, David. *The Path Between the Seas: The Creation of the Panama Canal 1870-1914*. New York: Simon & Schuster. 2004.

[41] "The Shuttle [requires] a large '*standing army*' of workers to keep it flying" (emphasis added. "Columbia Accident Investigation Board: Final Report." Volume I. p. 106. <http://caib.nasa.gov/news/report/pdf/vol1/full/caib_report_volume1.pdf>

[42] The analogy of space development to the historical development of the Panama Canal was developed by John Hickman, in "The political economy of very large space projects." *Journal of Evolution and Technology*. 1999. <http://jetpress.org/volume4/space.pdf>

[43] Charter of the Committee. Section 3.

[44] "Political, financial, legal, technical, social, operational, and organizational factors, including the stakeholders' perspectives and relationships, are considered in SoS [system of systems] development, management, and operations." <http://www.sosece.org/>

[45] Where economics is practiced as a *science*, and not a "cargo-cult religion." See: Bouchaud, J-P. "Economics needs a scientific revolution." *Nature* 2008;455:1181. <http://www.paecon.net/PAEReview/issue48/Bouchaud48.pdf>

[46] "Economics needs to be revamped to reflect our understanding of economic systems as nonequilibrium energy systems.... [Such energy systems] reside at some distance from equilibrium, produce entropy that is exported out of the system, and maintain a low-entropy level inside the system at the expense of disorder outside the system." Schneider, Eric and Dorion Sagan. *Into the cool: Energy flow, thermodynamics, and life*. Chicago, IL: University of Chicago Press. 2005. p. 275, 328.

[47] "Institutions are not rules. They are self-enforcing systems of rules, beliefs, norms, and organizations.... Successful reform requires much more than a change of rules; it requires creating new systems of interrelated institutional elements that motivate, enable, and guide individuals to take particular actions. Reform must first empirically identify, rather than assume, the transactions that are important for improving welfare.... When pursuing reforms, however, we have to recall that the very same cognitive, coordinative, normative, and informational factors that make institutions important determinants of behavior forestall devising institutional reforms." Greif, Avner. *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade*. Cambridge, UK: Cambridge University Press. 2006. p. 402-403.

[48] The Onion. "NASA Announces Plan To Launch $700 Million Into Space." 3 May 2006. <http://www.theonion.com/content/node/47977>

[49] The Constellation program aims to send astronauts to the moon and possibly on to Mars. It "is expected to cost upward of $230 billion." Government Accountability Office. "NASA: Assessment of selected large-scale projects." GAO-09-306SP. March 2009. p. 1.

[50] "The Commission believes that commercialization of space should become a primary focus of the vision, and that the creation of a space-based industry will be one of the principal benefits." E.C. "Pete" Aldridge, Jr., et al. "President's Commission on Implementation of United States Space Exploration Policy." 2004. p. 19-20. <http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf>

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[51] Commercial Spaceflight Federation. "Commercial Spaceflight in Low Earth Orbit is the Key to Affordable and Sustainable Exploration Beyond." 29 June 2009. <http://www.commercialspaceflight.org/pressreleases/Commercial%20Spaceflight%20Augustine%20White%20Paper%20-%206-29-09.pdf>

[52] The National Aeronautics and Space Act of 1958, As Amended, establishes the profitable utilization of space resources as its *primary* responsibility:

"Section 102. (c) The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration ... seek and encourage, to the maximum extent possible, *the fullest commercial use of space*."

Section 102 (a) indicates that the U.S. "should" pursue peaceful activities in space "for the benefit all mankind." Section 102 (b) undermines this goal, reserving for the Department of Defense "the development of weapons systems [and] military operations."
Section 102. (c) articulate the agency's commercial imperative (see above).
Section 102. (d) directs NASA to contribute to "one or more" of several diverse activities: expanding our knowledge of space; improving space vehicles; developing and operating space vehicles; studying potential *benefits derivable from space;* maintaining perceptions of U.S. leadership in space science, technology, and manufacturing; and cooperating with, and sharing knowledge with, other U.S. agencies and other nations.
Section 102. (e) and (f), oddly, direct NASA to conduct R&D for "petroleum-conserving ground propulsion systems" and "bioengineering," which have nothing to do with space.
Section 102. (g), the final space-related directive, assigns NASA the task of "detecting, tracking, cataloguing, and characterizing *near-Earth asteroids* and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth." (Emphasis added.) <http://history.nasa.gov/spaceact-legishistory.pdf>

[53] "NASA's current approach *does not address* the objectives and recommendations outlined by the Aldridge Commission in *the crucial areas of commercial space*." (Emphasis added.) <http://restorethevision.blogspot.com/2009/07/how-far-is-esas-architecture-from.html>

[54] Congressional Budget Office. "The budgetary implications of NASA's current plans for space exploration." April 2009.

[55] Government Accountability Office. "NASA: Assessment."

[56] "Institutions are the engine of history.... [They] constitute much of the structure that influences behavior, including behavior leading to new institutions.... An institution can *remain self-enforcing* even if the behavior it generates is *no longer efficiency-enhancing*" (emphasis added). Greif. *Institutions*. 2006. p. 379, 381.

[57] Fritz Lang's *Die Frau im Mond* uses this plot device: astronauts seek the moon's gold.

[58] Buzz Aldrin (Apollo 11 astronaut) with David Noland. "Buzz Aldrin to NASA: U.S. space policy is on the wrong track." *Popular Mechanics*. August 2009. <http://www.popularmechanics.com/science/air_space/4322647.html>

[59] "Why are we doing that again, spending billions of dollars on that again? Setting up a base [on the moon] is absolutely ridiculous. It's so ridiculous, it's laughable." Rusty Schweickart, Apollo 9 astronaut. Simerman, John. *Contra Costa Times*. 19 July 2009. <http://www.contracostatimes.com/ci_12867400>

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[60] Canup, R. "Simulations of a late lunar-forming impact." *Icarus* 2004;168(2):433-456. <http://www.boulder.swri.edu/~robin/c03finalrev.pdf>

[61] For 3.4 billion years of evolution on Earth, the mass of the planet has generated, at its surface, a gravitational field of 976 to 983 *Galileos* (a unit of acceleration defined as one centimeter per second squared) from sea level to mountain top (a range of less than 1%). Given that such a narrow range of gravitational force has informed the entire span of life on Earth, and the radical dysfunction of biomolecular systems when removed from this field (in one experiment regarding immune system function in zero-G [gene expression in T-cells] 90 of 99 genes required for normal biological health *failed to be expressed*), it is unlikely that the weak gravitational fields generated by the moon and Mars will be sufficient for biological health. The moon offers only one-sixth Earth-normal gravity, Mars just one-third (~160 and ~335 Galileos, respectively).

"The molecular and cellular structure of *life on Earth may require gravity for survival,* either in individual or in evolutionary terms [as in generational procreation], and it is therefore possible that exactly such gravity-dependent or gravity-sensing mechanisms will keep us dependent from the gravity field of Earth" (emphasis added). Ullrich, Oliver and Donat-P. Häder. "Editorial: Signal transduction in gravity perception: From microorganisms to mammals." *Signal Transduction* 2006;6(6):377-9.

See also: Boonyaratanakornkit J., A. Cogoli, C.-F. Li, et al. "Key gravity-sensitive signaling pathways drive T cell activation." *The Federation of American Societies for Experimental Biology Journal* 2005;19(14):2020-2022. <http://www.fasebj.org/cgi/reprint/05-3778fjev1.pdf>

Gridley DS, Slater JM, Luo-Owen X, et al. "Spaceflight effects on T lymphocyte distribution, function and gene expression." *Journal of Applied Physiology*. 2009;106:194-202.

[62] Brumfiel G. "Special Report: Fusion dreams delayed." *Nature* 2009;459:488-489.

[63] "Kalpana One is intended to improve on the space settlement designs of the mid-1970s: the Bernal Sphere, Stanford Torus, and O'Neill cylinders, as well as on Lewis One, designed at NASA Ames Research Center in the early 1990s. These systems are intended to provide permanent homes for communities of thousands of people. The Kalpana One structure is a cylinder with a radius of 250m and a length of 325m.... Kalpana One is intended to be the first, and smallest, of a family of space settlements. The size is determined by the limited rotation rate humans are assumed to tolerate, 2rpm. The rotation rate drives the radius to achieve 1g pseudo-gravity, and the radius drives the length due to angular moment of inertia requirements. For later, larger settlements in the Kalpana family, the rotation rate may be reduced, increasing the radius and the allowable length." Globus A, Arora N, Bajoria A, Straut J. "The Kalpana One Orbital Space Settlement—Revised." American Institute of Aeronautics and Astronautics. 2007. p. 1, 10. <http://alglobus.net/NASAwork/papers/2007KalpanaOne.pdf>

[64] Thanks to Apollo astronaut Rusty Schweickart, founder of the B612 Foundation, and to the Association of Space Explorers (ASE), progress is being made on devising a functional global response to a real potential asteroid impact. Just this year, The Working Group on Near-Earth Objects of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space "agreed that the report of [the] ASE

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["Asteroid Threats: A Call For Global Response"] served as a good basis for advancing the implementation of the workplan of the Working Group to continue drafting, and seek agreement on, international procedures for handling the NEO threat." Committee on the Peaceful Uses of Outer Space, 52nd Session. Vienna, 3-12 June 2009. Report of the Scientific and Technical Subcommittee, 46th Session. Vienna, 9-20 February 2009. p. 36. <http://www.oosa.unvienna.org/pdf/reports/ac105/AC105_933E.pdf>

ASE Report: <http://www.space-explorers.org/ATACGR.pdf>
B612 Foundation: < http://www.b612foundation.org/>

[65] The Hayabusa mission was designed to conduct "experimental research on new engineering technologies necessary for returning planetary samples (sample return) to earth including electrical propulsion, autonomous navigation, sampler, and reentry capsule." Japan Aerospace Exploration Agency. "Hayabusa Mission Profile." <http://www.isas.jaxa.jp/e/enterp/missions/hayabusa/>

[66] "The main objective ... is to return a sample from a Near-Earth Object (NEO) ... to Earth." Marco Polo: Science Requirements Document. 20 May 2009. p. 6. <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42795>

[67] A rendezvous with 945 identified near-Earth asteroids (as of July 2009) will require less energy than a rendezvous with the moon. Source data: Benner, Lance. "Delta-v for spacecraft rendezvous with all known near-Earth asteroids (q < 1.3 AU)." NASA JPL. <http://echo.jpl.nasa.gov/~lance/delta_v/delta_v.rendezvous.html>

[68] LSST: Large Synoptic Survey Telescope. <http://www.lsst.org/>
Pan-STARRS: The Panoramic Survey Telescope & Rapid Response System. <http://pan-starrs.ifa.hawaii.edu/public/>

[69] "Advances in observing technology will lead to the detection of over 500,000 NEOs over the next 15 years." Schweickart R, Jones T, von der Dunk F, et al. "Asteroid threats: A call for global response." Association of Space Explorers. 2008. p. 3. <http://www.space-explorers.org/ATACGR.pdf>

[70] Rayl, AJS. "Hayabusa: Spacecraft lands on asteroid for second time and snatches sample." The Planetary Society. 26 November 2005. <http://www.planetary.org/news/2005/1126_Hayabusa_Spacecraft_Lands_on_Asteroid.html>

[71] Campbell, Colin. "Understanding peak oil." <http://www.peakoil.net/about-peak-oil>

[72] U.S. Geological Survey. "Mineral Commodity Summaries: 2009." p. 6. <http://minerals.usgs.gov/minerals/pubs/mcs/2009/mcs2009.pdf>

[73] The National Research Council of The National Academies, The Committee on Earth Resources. *Minerals, Critical Minerals, and the U.S. Economy*. The National Academies Press. 2008. <http://books.nap.edu/catalog.php?record_id=12034>

[74] Schwank, Johannes. Quoted in Tollefson, Jeff. "Worth its weight in platinum." *Nature* 2007;450:334-335.

[75] See: Gordon RB, Bertram M, Graedel TE. "Metal stocks and sustainability." *PNAS*. 2006;103(5):1209-1214. <www.pnas.org/cgi/doi/10.1073/pnas.0509498103>

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Halada, Kohmei, Masanori Shimada, and Kiyoshi Ijima. “Forecasting the Consumption of Metals up to 2050.” *Journal of the Japan Institute of Metals*. 2007;71(10):831-839. <http://www.jstage.jst.go.jp/article/jinstmet/71/10/71_831/_article>

[76] “The majority of the world’s PGE reserves are held in a handful of deposits, most of which occur within the unique Bushveld Complex of South Africa.” Mungall, James. “Ore deposits of the platinum-group elements.” *Elements* 2008;4(4):253-258.

[77] Johnson Matthey. Platinum Today. Market Data Charts: 2008.
Platinum: <http://www.platinum.matthey.com/publications/122754114732474.html>
Rhodium: <http://www.platinum.matthey.com/publications/122754127332740.html>

[78] Johnson Matthey. Platinum Today. Price Charts.
<http://www.platinum.matthey.com/prices/price_charts.html>

[79] Ritter, S. “Future of metals.” *Chemical & Engineering News* 2009;87(32):53-57.

[80] The details of this argument are presented in a forthcoming book: *The Wealth of Asteroids: Incorporating Near-Earth Resources into the Human Economy*. Draft chapters are online: <http://www.abundantplanet.org/WealthOfAsteroids>

[81] Service, Robert. “Hydrogen cars: Fad or the future?” *Science* 2009;324:1257-1259.

[82] “For the DoD specifically, beamed energy from space in quantities greater than 5 MWe has the potential to be a disruptive game changer on the battlefield. SBSP and its enabling wireless power transmission technology could facilitate extremely flexible ‘energy on demand’ for combat units and installations across an entire theater, while significantly reducing dependence on vulnerable over-land fuel deliveries.... SBSP could provide the ability to deliver rapid and sustainable humanitarian energy to a disaster area or to a local population undergoing nation-building activities.... [The DoD appears to spend] *more than $1/kWh* in forward deployed locations” (emphasis added). National Security Space Office. “Space-based solar power as an opportunity for strategic security.” 2007. p. 3, 34. <http://www.acq.osd.mil/nsso/solar/SBSPInterimAssesment0.1.pdf> For comparison, average 2009 residential prices for electricity are one-tenth as much: 11 to 12¢/kWh. <http://www.eia.doe.gov/emeu/steo/pub/gifs/Fig21.gif>

[83] “A single kilometer-wide band of geosynchronous earth orbit experiences enough solar flux in one year (approximately 212 terawatt-years) to nearly equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today (approximately 250 TW-yrs).” National Security Space Office. “SBSP.” 2007. p. 5.

[84] Last December, *The Economist* published a letter that I wrote suggesting that rather “than build and then launch, we should launch and then build,” using NEA materials to build space-based solar power systems.
<http://www.economist.com/opinion/displaystory.cfm?story_id=12811605#celestial_bodies>

[85] The Nikkei. “Japan Shooting For Space-Based Solar Power.” 28 June 2009.
<http://www.nni.nikkei.co.jp/e/fr/tnks/Nni20090627D27JFF04.htm>

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[86] For example, the fact that SpaceX has completed 14 of 14 milestones is *noted* at NASA's Commercial Crew and Cargo Program Office web page, under their Commercial Orbital Transportation Services (COTS) projects, but one needs to read a Government Accountability Office (GAO) report to learn that "SpaceX *successfully completed* its first 14 development milestones *on time*." p. 18. This success should be celebrated, not just "noted" on an out of date web page. <http://www.gao.gov/new.items/d09618.pdf> NASA's page: <http://www.nasa.gov/offices/c3po/partners/spacex/index.html>

[87] The mission of the U.S. Geological Survey (USGS) is to serve "the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; *manage water, biological, energy, and mineral resources;* and enhance and protect our quality of life" (emphasis added). <http://www.usgs.gov/aboutusgs/>

[88] The mission of the Bureau of Economic, Energy, and Business Affairs in the U.S. State Department is to "*promote economic security and prosperity* at home and abroad.... As the single point where international economic policy tools and threads converge, we help promote a coherent economic policy across the U.S. Government" (emphasis added). <http://www.state.gov/e/eeb/index.htm>

Specifically, "The Office of Economic Policy Analysis & Public Diplomacy works to *develop and promote sound economic policies by analyzing* the effectiveness of current U.S. policies, engaging the private sector in policy planning and development, and by evaluating economic and foreign policy implications of *emerging, cross-cutting issues*" (emphasis added). <http://www.state.gov/e/eeb/eppd/index.htm>

[89] Moltz. *The Politics of Space Security*. 2008. p. 11, 7.

[90] "Approximately 19,000 objects larger than 10 cm are known to exist. The estimated population of particles between 1 and 10 cm in diameter is approximately 500,000. The number of particles smaller than 1 cm probably exceeds tens of millions." NASA Orbital Debris Program Office. <http://orbitaldebris.jsc.nasa.gov/faqs.html>

The Inter-Agency Space Debris Coordination Committee, an eleven-agency organization that reports to the UN COPUOS annually, notes that even if we ceased all launches today, *orbital debris would increase,* due to a cascade effect, through this century and beyond. "Status of Activity of the Inter-Agency Space Debris Coordination Committee." 7-8 February 2008. p. 2. <http://www.iadc-online.org/docs_pub/IADC-08-01.pdf>

"At orbital speeds, even tiny fragments—such as bolts and shards of metal of about four inches [10 cm] in length—carry a tremendous violent force, equivalent to that of a 10-ton truck traveling at 118 mph." Moltz. *The Politics of Space Security*. 2008. p. 53.

[91] "The strongest argument against putting American weapons in space is that it will weaken rather than enhance our national security." Caldicott, H. and C. Eisendrath. *War in Heaven: The Arms Race in Outer Space*. New York: The New Press. 2007. p. 83.

"In light of the U.S. and Chinese decisions to explore at least limited space weapons programs [there is a] need for a renewed and expanded international dialogue about space security.... Great care will be required to manage this important experiment in environmental security, technological development, and human conflict prevention." Moltz. *The Politics of Space Security*. 2008. p. 329.

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An ongoing debate regarding space weaponization and security can be observed at the *Air & Space Power Journal*. "The professional journal of the United States Air Force." <http://www.airpower.maxwell.af.mil/airchronicles/apje.html>

[92] Globus, et al. "Kalpana One."

[93] Pan-STARRS: <http://pan-starrs.ifa.hawaii.edu/public/>
LSST: <http://www.lsst.org/>

[94] Weiss, Peter, Winnie Leung, and Tze-chuen Ng. "Houyi Mission Proposal: Asteroid Apophis Tracking and Sampling System." <http://planetary.s3.amazonaws.com/projects/apophis_competition/apophis_winner_houyi.pdf> Houyi received an "Honorable Mention," for most innovative student proposal in The Planetary Society's $50,000 Apophis Mission Design Competition. <http://www.planetary.org/programs/projects/apophis_competition/winners.html>

[95] Regolith Excavation Challenge. A NASA Centennial Challenge. NASA Research Park, Moffett Field, California. 17-18 October 2009. <http://www.regolith.csewi.org>

[96] Garrick-Bethell, Ian, and Christopher Carr. "Working and walking on small asteroids with circumferential ropes." *Acta Astronautica* 2007;61:1130-1135. <http://web.mit.edu/iang/www/pubs/working_asteroids.pdf>

[97] Doyle, Richard, et al. "Progress on AI, Robotics, and Automation in Space: A Report from [International Symposium on Artificial Intelligence, Robotics and Automation in Space] 2008." *IEEE Intelligent Systems* 2009;24(1):78-83 <doi:10.1109/MIS.2009.16>

Kubota, Takashi, et al. "Locomotion mechanism of intelligent unmanned explorer for deep space exploration." In Budiyono, Agus, et al. editors. *Intelligent Unmanned Systems: Theory and Applications*. Berlin, Germany: Springer-Verlag. 2009.

[98] "Property Rights in Space. Recommendation 5-2: The Commission recommends that Congress increase the potential for commercial opportunities ... [by] *assuring appropriate property rights* for those who seek to develop space resources and infrastructure" (emphasis added). Aldridge. "President's Commission." 2004. p. 33.

[99] "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." The Outer Space Treaty, officially the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," entered into force in 1967. As of January 2008, 98 states have ratified, and an additional 27 have signed, the Outer Space Treaty. <http://www.oosa.unvienna.org/oosa/SpaceLaw/outerspt.html>

[100] Pop, Virgiliu. *Who Owns the Moon? Extraterrestrial Aspects of Land and Mineral Resources Ownership*. Berlin, Germany: Springer Science+Business. 2009.

Cherian, Jijo and Job Abraham. "Concept of private property in space: An analysis." *Journal of International Commercial Law and Technology* 2007;2(4):211-220. <http://www.jiclt.com/index.php/jiclt/article/view/34/33>

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